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Report 2

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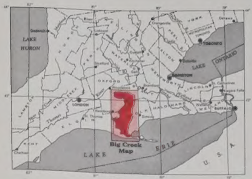
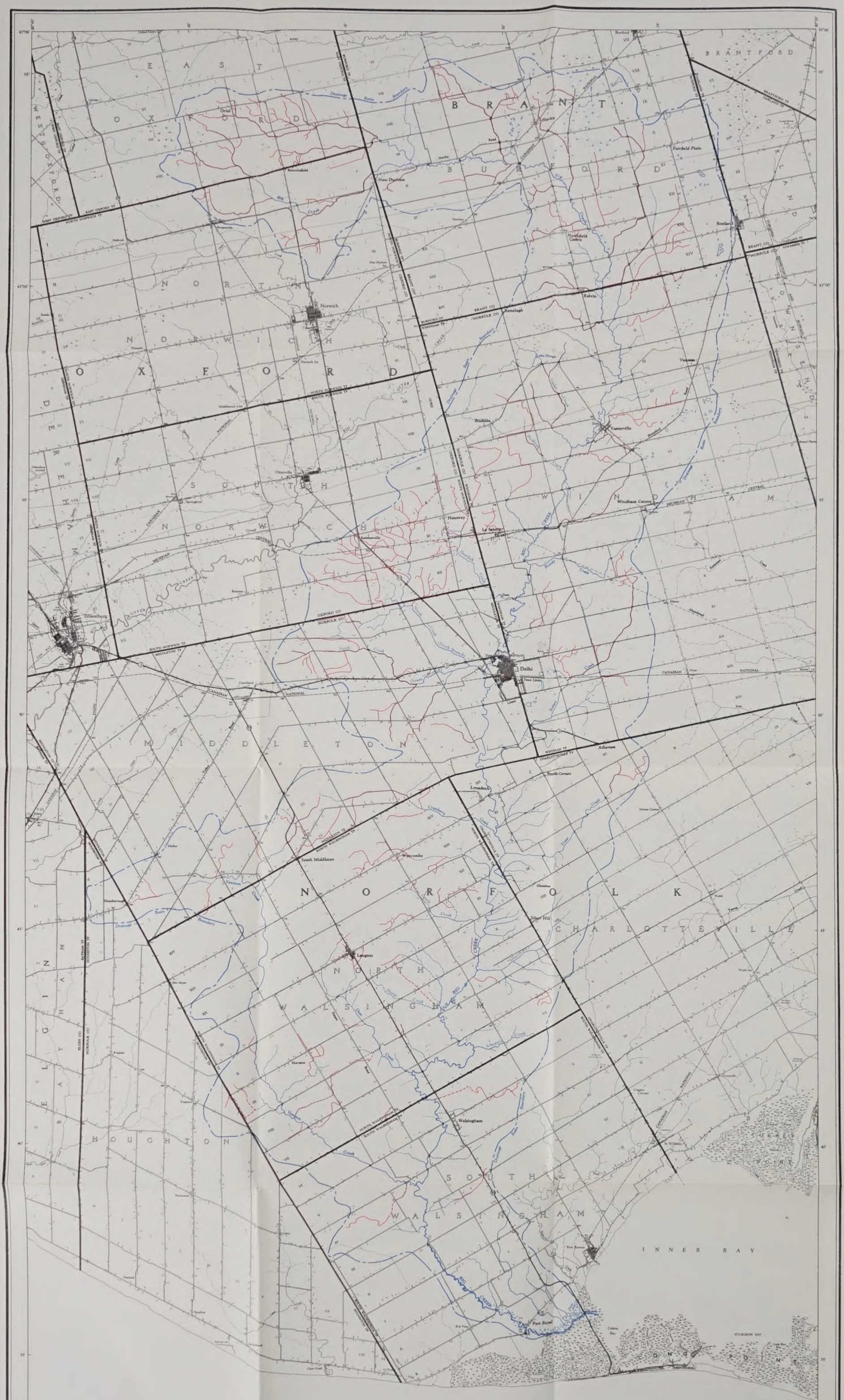
Water Resources of the Big Creek Drainage Basin



KEY MAP

Scale 1 inch to 50 miles



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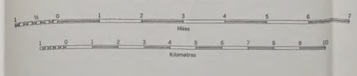
Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch



LEGEND

Drainage Works.

Probable discharge course of drainage works.

Note: All works shown were constructed since 1953 under the following Acts:
The Municipal Drainage Act,
The Ditches and Watercourses Act, or
The Drainage Act.

SOURCES OF INFORMATION

Records on file with the Department of Municipal Affairs and local municipalities.

Cartography by H. A. Flotner and S. Impey, 1965.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

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ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

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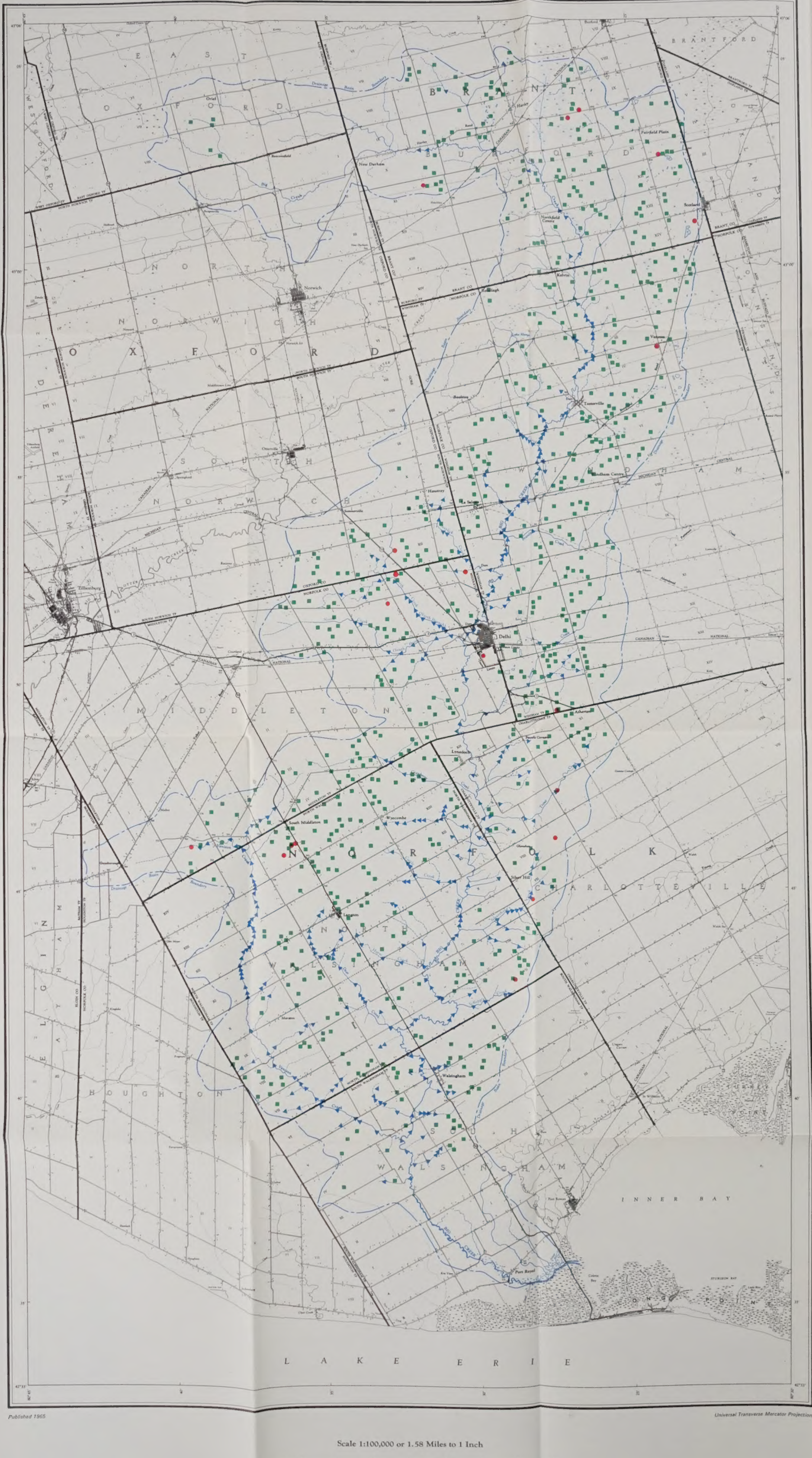
WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-8

DRAINAGE WORKS



Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

- ▲ Taking from stream or lake.
- ● Taking from well or well-point system.
- ■ Taking from dugout.

SOURCES OF INFORMATION

Water Permit Records on file with the Ontario Water Resources Commission.

Cartography by H. A. Flotner, 1964.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

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WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-6

LOCATIONS OF WATER TAKINGS AUTHORIZED BY PERMITS

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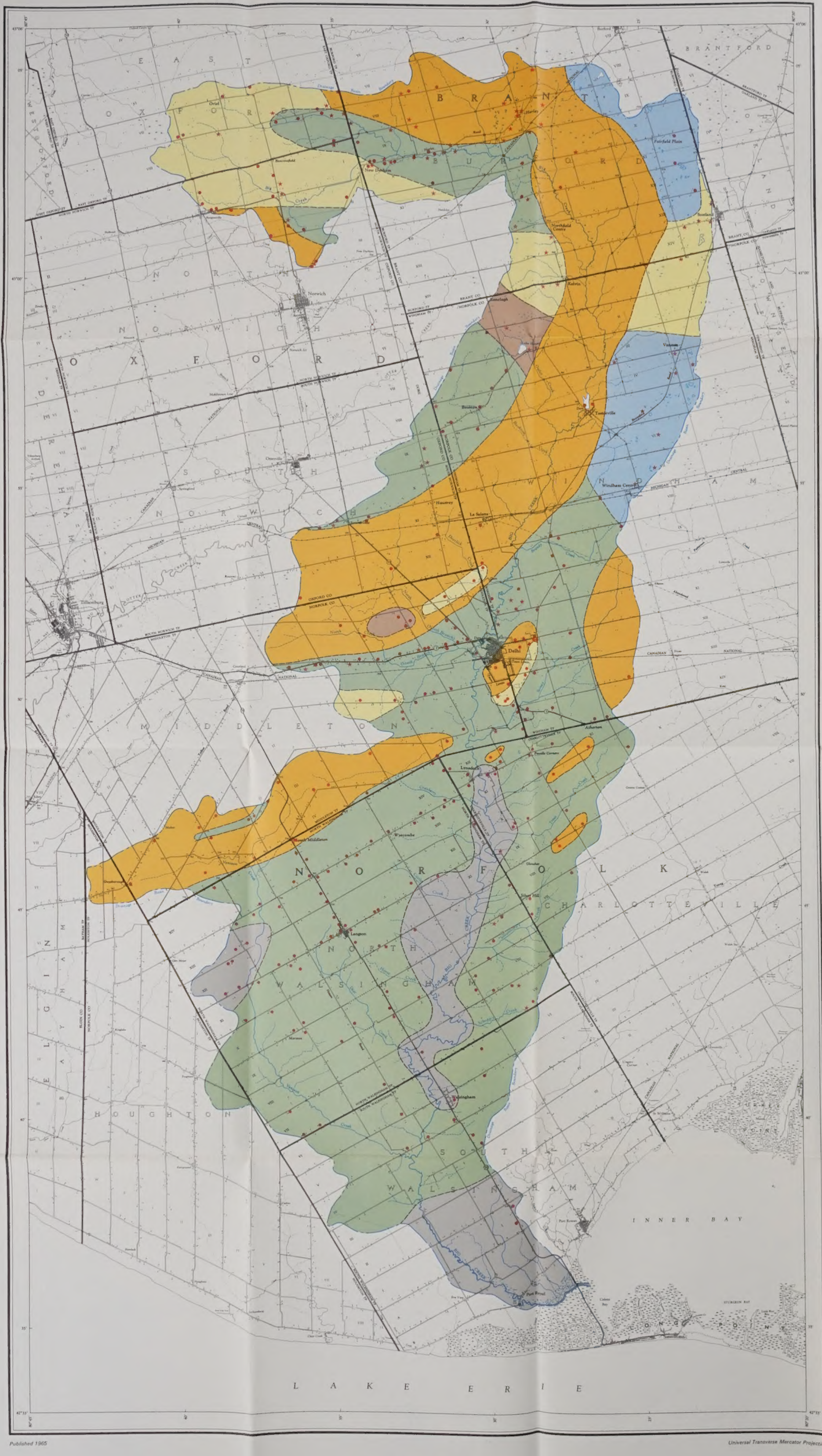

Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

Areas where wells are likely to produce less than 3 gpm (gallons per minute). Difficulties are encountered in obtaining sufficient quantities of good quality water for any purpose. Yields are limited by low permeabilities of aquifers or by thin saturated thicknesses of overburden aquifers.

Areas where wells are likely to produce 3 to 10 gpm. Supplies are generally sufficient for domestic and stock purposes. Aquifers are mainly fine sand of low permeability. In the southern parts of the basin dugout ponds may be adequate for irrigation purposes. Bedrock aquifers in these areas generally yield mineralized water.

Areas where wells are likely to produce 10 to 25 gpm. Supplies are generally plentiful for domestic and stock purposes but poor to fair as supplemental sources for irrigation. Aquifers are generally fine to coarse sand. Many of the areas are favourable sources for dugout ponds. In the extreme northern end the bedrock is the main aquifer. Yields are limited by low to moderate permeabilities.

Areas where wells are likely to produce 25 to 50 gpm. Supplies may be fair to good for municipal purposes and fair as supplemental sources for irrigation. In the central regions the aquifers are mainly medium to coarse sand with occasional gravel. In the northern regions the aquifers are sand and gravel above the bedrock and the bedrock. Yields are limited by the areal extent of the aquifers.

Areas where wells are likely to yield 50 to 100 gpm. Supplies may be suitable for municipal or irrigation purposes. Aquifers are sand and gravel or bedrock. Yields are limited by areal extent of the aquifers.

Areas where wells are likely to produce more than 100 gpm. Supplies are suitable for most purposes. Aquifers are sand and gravel in the Fairfield Plain area and bedrock near Windham Centre. Aquifers have high permeabilities but the yields from the overburden may be limited in some localities by thin saturated thicknesses.

Note: The probable yield indicated for each area represents the production of generally satisfactory quality water that can be expected from individual wells based on geology and short-term pumping tests and may not necessarily represent long-term yields.

SYMBOLS

Well where an overburden aquifer is source of probable yield.

Well where a bedrock aquifer is source of probable yield.

SOURCES OF INFORMATION

Availability of groundwater by T. J. Yakutchik and U. Sibul, 1965.

Well information from:
Water Well Records on file with the Ontario Water Resources Commission.

Cartography by H. A. Flotner and S. Impey, 1965.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

Ontario

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WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-5

AVAILABILITY OF GROUND WATER

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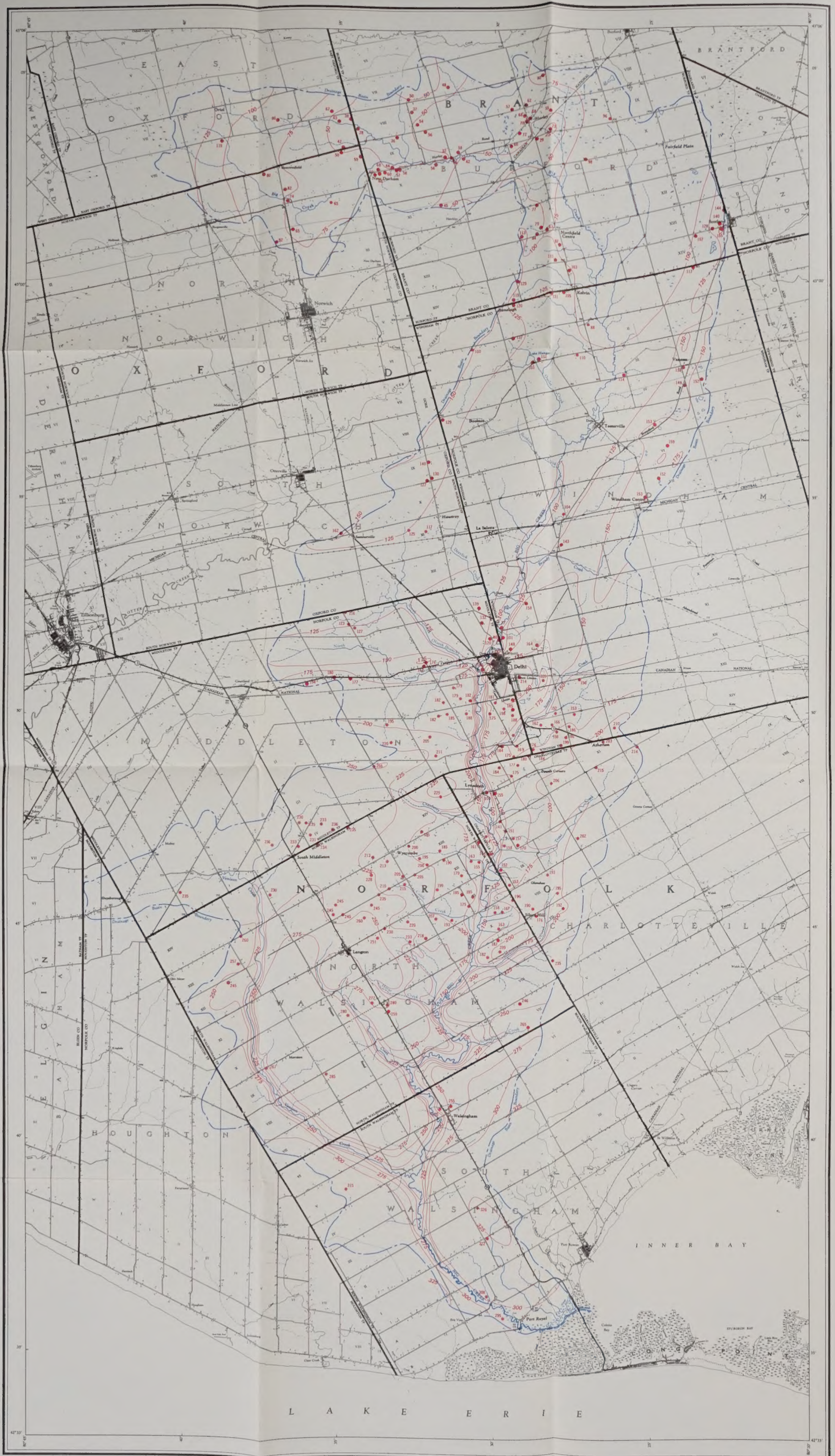

Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

—150—	*Line of equal overburden thickness (isopach), interval 25 feet.*
•	*Water well.*
•	*Oil or gas well.*
164	*Thickness of overburden at well in feet.*

SOURCES OF INFORMATION

Thickness of overburden by T. J. Yakutchik and U. Sibul, 1964.

Reference:

Map 53-31, Norfolk County drift-thickness and bedrock contours, by B. V. Sanford; Geological Survey of Canada, 1954.

Well information from:

Water Well Records on file with the Ontario Water Resources Commission.

Oil and Gas Well Records on file with the Ontario Department of Energy and Resources Management.

Cartography by H. A. Flotner, 1964.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

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ONTARIO WATER RESOURCES COMMISSION

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WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-4

THICKNESS OF OVERBURDEN

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LEGEND

CENOZOIC

PLEISTOCENE

RECENT

ALLUVIAL DEPOSITS: Chiefly fine sand along flood plain of Big Creek. Will yield small to moderate quantities of water.

MARSH-SWAMP DEPOSITS: Mainly organic matter, some silt.

WISCONSINAN

BEACH DEPOSITS: Mainly sand and gravel and some fine sand, marked by sorting and parallel stratification. Occur along morainic ridges at Windham Centre, south of Otterville, near Mabee and southeast of Delhi. Are closely associated with outwash deposits. Highly permeable but yields limited by small saturated thicknesses.

SHALLOW LACUSTRINE AND FLUVIAL DEPOSITS: Mainly fine to medium sand with local coarser phases at depth, characterized by cross-bedding. Occur in broad flat areas between morainic ridges. Deposits consist of sand and gravel in parts of the Township of Burford which grade into medium to fine sand southward. Will yield moderate to very large quantities of water.

OUTWASH DEPOSITS: Mainly sand and gravel with little fine sand or silt, characterized by areal and vertical variations in grain size and sorting. Occur sporadically along ridge from Delhi to Scotland and extensively north and northwest of Scotland. Highly permeable and capable of largest yields of the overburden aquifers especially north of Scotland. Yields are limited in other areas by small saturated thicknesses.

MORAINIC DEPOSITS (Undifferentiated): Mainly till, unsorted mixtures of gravel, sand, silt and clay in varying proportions but may contain small pockets of sorted and stratified material. Occurs as moraine and ground moraine. Two tills are exposed. An upper stony, sandy, silty till forms the resistent cap on the morainic ridges and occurs occasionally below the top sand in the southern part of the basin. A lower clayey till occurs sporadically at depth throughout the basin and outcrops in stream valleys and in the southern part of the Township of South Walsingham. Relatively impermeable but may yield small quantities of water to dug or bored wells.
Some till has been reworked or modified by water action and may be locally sorted. Difficult to differentiate from outwash or till. Occurs along flanks of morainic ridges and on plain between Burgessville and New Durham. May yield small quantities of water.

LACUSTRINE DEPOSITS (Undifferentiated): Mainly fine sand, silt and clay, characterized by high degree of sorting and horizontal stratification. Two series are exposed; an upper, which contains abundant fine sand, and a lower, which is more compact, locally contorted and contains abundant silt and clay. Both appear to occur throughout most of the basin except where removed or altered by spillway action. Yields vary from small to moderate for the upper series and are usually small for the lower series. Yields are limited by poor permeability of fine-grained sediments.

SYMBOLS

Geological boundary, approximate.

Topographic contour.

Raised shoreline, observed and inferred.

Gravel pit.

SOURCES OF INFORMATION

Surficial geology by T. J. Yakutchik and U. Sibul, 1964.

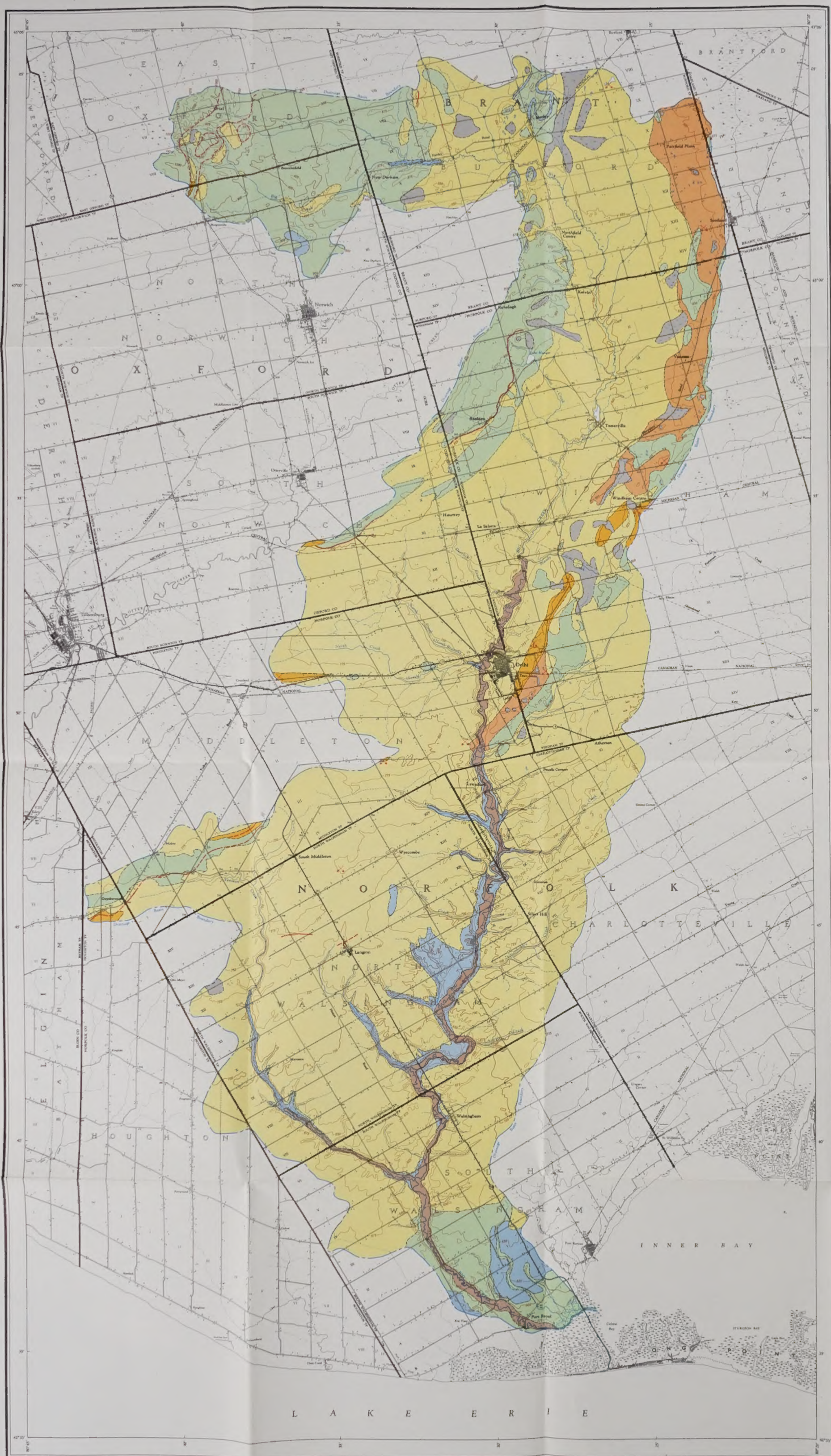
References:

The Physiography of Southern Ontario, by L. J. Chapman and D. F. Putnam, 1951.

Field notes on surficial geology of Township of Windham by A. K. Watt, 1949.

Cartography by H. A. Flotner and S. Impey, 1965.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.



Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

1 ½ 0 1 2 3 4 5 6 7
Miles

1 0 1 2 3 4 5 6 7 8 9 10
Kilometres

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WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-3

SURFICIAL GEOLOGY

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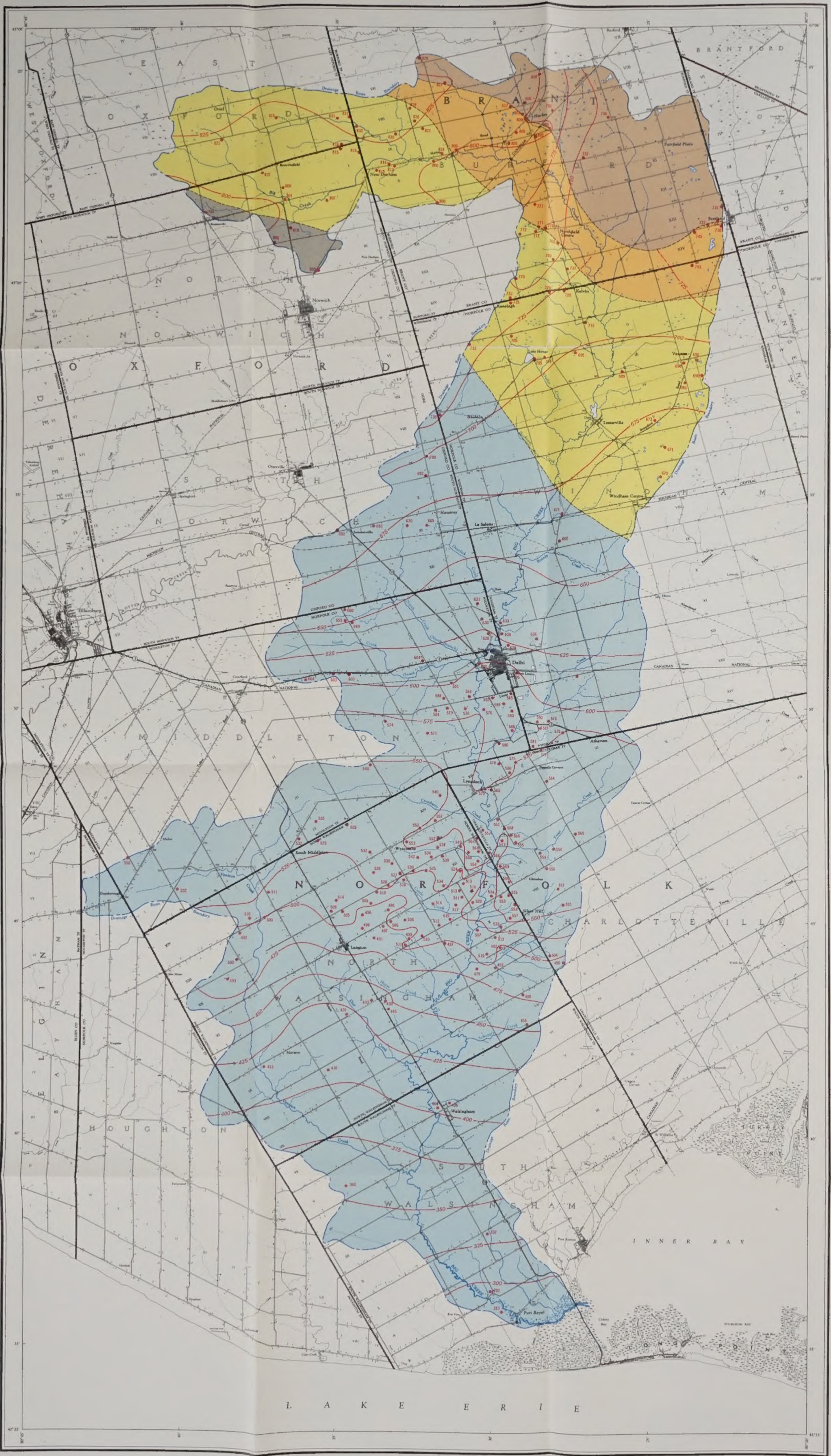

Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

PALÆOZOIC

DEVONIAN

DELAWARE FORMATION: brown and buff limestone, some chert.

DETROIT RIVER GROUP: brown and buff limestone and dolomite, sandstone.

BOIS BLANC FORMATION: limestone, dolomite and chert, sandstone.

SILURIAN

BASS ISLAND FORMATION: cream and buff dolomite.

SALINA FORMATION: buff to brown dolomite and limestone, grey dolomitic shale, anhydrite, gypsum and salt.

SYMBOLS

Geological boundary, approximate.

750 *Bedrock surface contour, interval 25 feet.*

Water well in bedrock.

Oil or gas well in bedrock.

506 *Elevation of bedrock surface at well.*

Note: All elevations in feet above mean sea level.

SOURCES OF INFORMATION

Bedrock topography by T. J. Yakutchik and U. Sibul, 1964.

Reference:

Map 53-31, Norfolk County drift-thickness and bedrock contours, by B. V. Sanford; Geological Survey of Canada, 1954.

Bedrock geology by T. J. Yakutchik, 1964; on the basis of oil and gas well logs assembled by the Ontario Department of Energy and Resources Management with the co-operation of the Geological Survey of Canada.

Reference:

Map 1062A, Southwestern Ontario, by B. V. Sanford; Geological Survey of Canada, 1958.

Well information from:

Water Well Records on file with the Ontario Water Resources Commission.

Oil and Gas Well Records on file with the Ontario Department of Energy and Resources Management.

Cartography by H. A. Flotner, 1964.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

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ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-2

BEDROCK GEOLOGY AND TOPOGRAPHY

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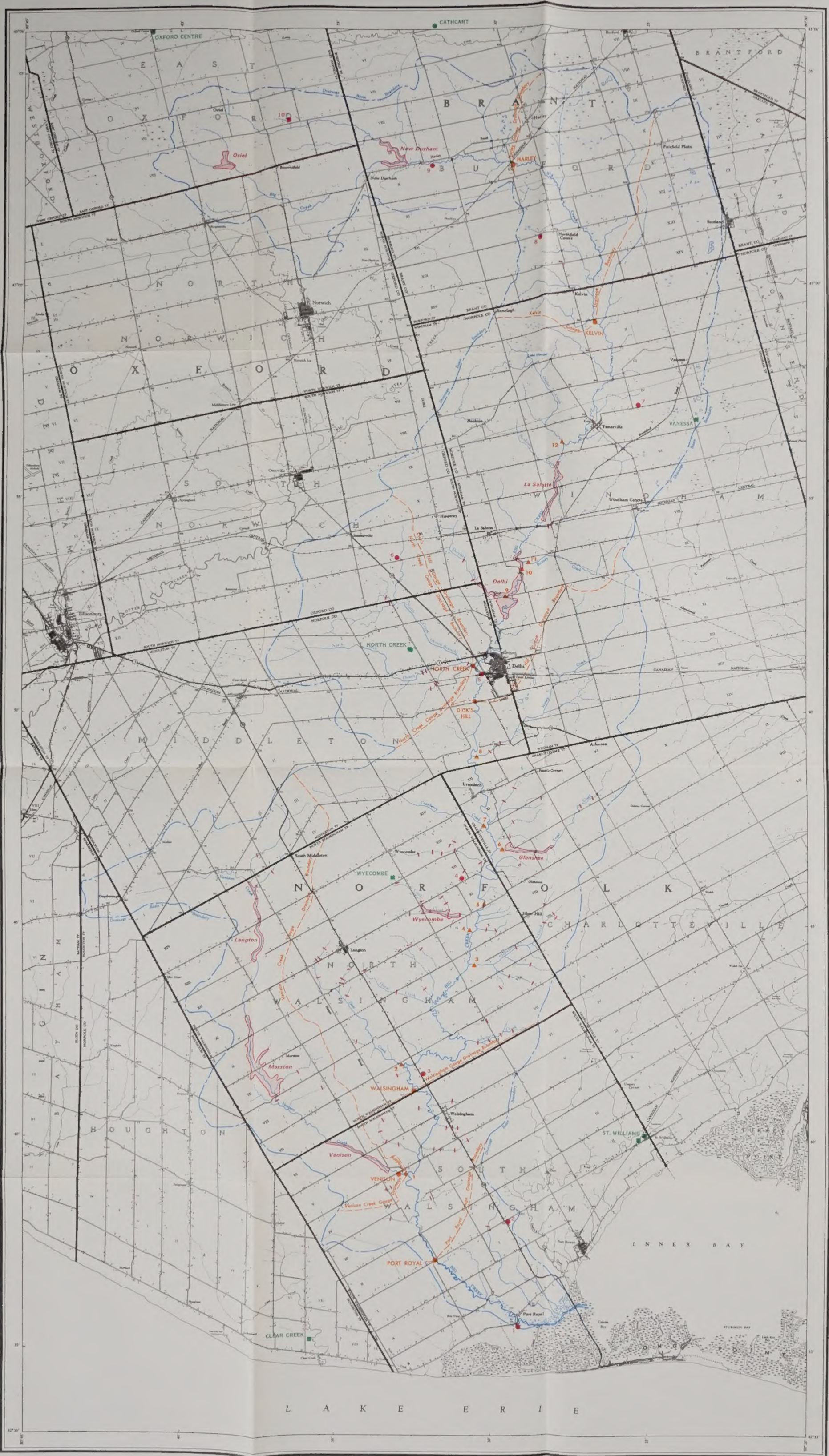

Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

● HARLEY	Streamflow gauging station, recording gauge.
■ NORTH CREEK	Streamflow gauging station, manual gauge.
▲ 4	Streamflow station, periodic discharge measurement.
● CATHCART	Meteorological station, permanent.
■ VANESSA	Meteorological station, seasonal.
● 7	Observation well.
	Existing dam.
Delhi	Proposed reservoir site.
	Minor drainage boundary.

For other conventional signs refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Field Survey by B. A. Singh and assistants, 1964.

Hydrometric station data from Department of Northern Affairs and National Resources, Canada Department of Transport, Ontario Department of Agriculture, Ontario Water Resources Commission.

Dam and reservoir data from Department of Energy and Resources Management, Department of Lands and Forests and Big Creek Region Conservation Authority.

Cartography by H. A. Flotner, 1964.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

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DIVISION OF WATER RESOURCES

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WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-7

HYDROMETRIC STATIONS, DAMS AND PROPOSED RESERVOIR SITES

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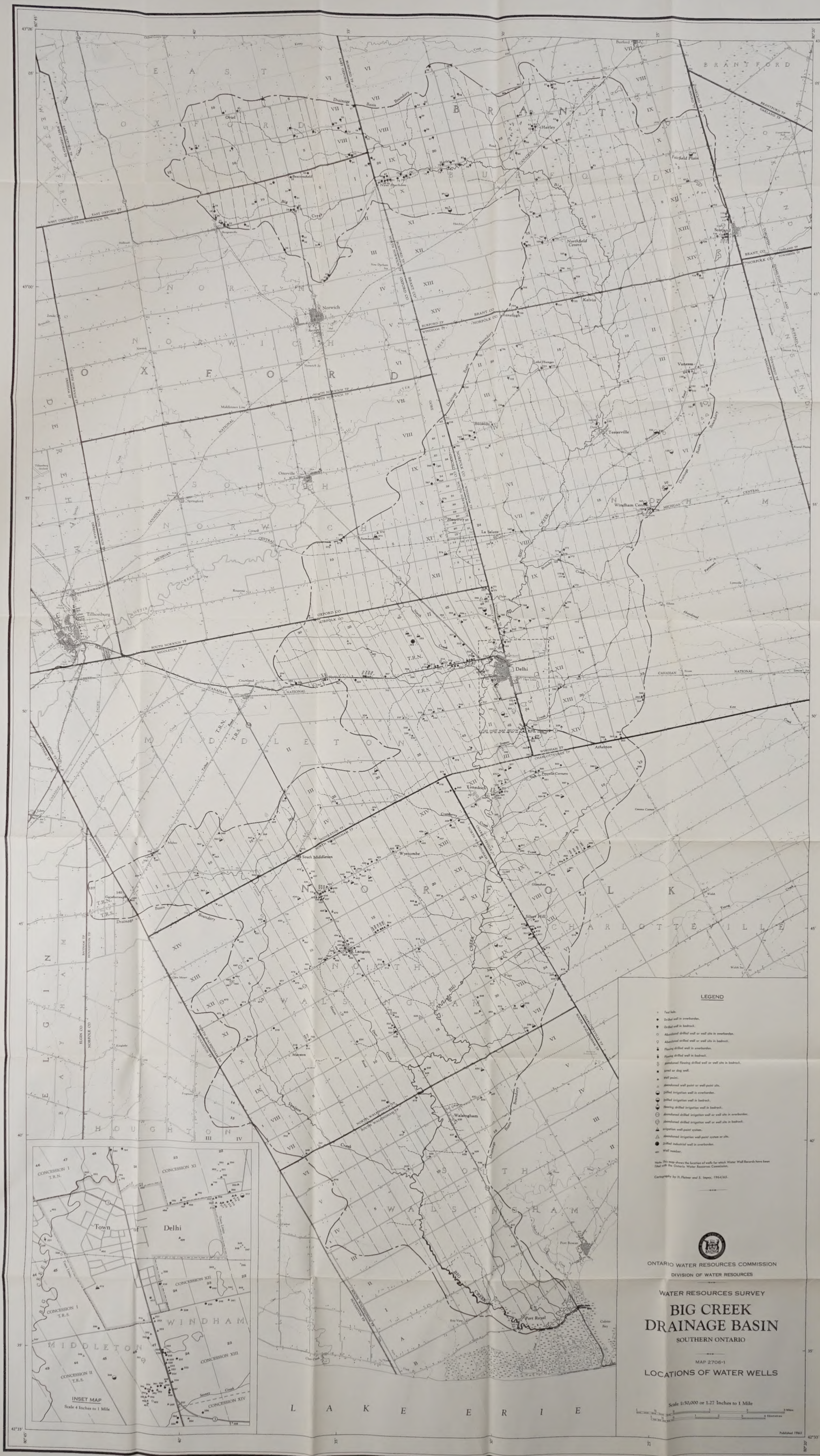

LEGEND
Test hole.
Drilled well in overburden.
Drilled well in bedrock.
Abandoned drilled well or well site in overburden.
Abandoned drilled well or well site in bedrock.
Flowing drilled well in overburden.
Flowing drilled well in bedrock.
Abandoned flowing drilled well or well site in bedrock.
Bored or dug well.
Well point.
Abandoned well point or well-point site.
Drilled irrigation well in overburden.
Drilled irrigation well in bedrock.
Flowing drilled irrigation well in bedrock.
Abandoned drilled irrigation well or well site in overburden.
Abandoned drilled irrigation well or well site in bedrock.
Irrigation well-point system.
Abandoned irrigation well-point system or site.
Drilled industrial well in overburden.
Well number.
Note: This map shows the location of wells for which Water Well Records have been filed with the Ontario Water Resources Commission.
Cartography by H. Flatner and S. Impey, 1964/65.
ONTARIO WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES
WATER RESOURCES SURVEY
BIG CREEK DRAINAGE BASIN
SOUTHERN ONTARIO
MAP 2706-1
LOCATIONS OF WATER WELLS
Scale 1:50,000 or 1.27 Inches to 1 Mile
Published 1965
INSET MAP
Scale 4 Inches to 1 Mile
Town of Delhi
CONCESSION I T.R.N.
CONCESSION XI
CONCESSION XII
CONCESSION I T.R.S.
CONCESSION II T.R.S.
CONCESSION XIII
CONCESSION XIV
WINDHAM
MIDDLETON
OXFORD
NORFOLK
BRANTFORD
EAST OXFORD
NORTH NORWICH
SOUTH NORWICH
BURFORD
WINDHAM
MIDDLETON
NORTH WALSINGHAM
SOUTH WALSINGHAM
CHARLOTTEVILLE
Norwich
Otterville
Tillsonburg
Delhi
Langton
Walsingham
Port Royal
Scotland
Hatley
Fairfield Plain
Northfield Centre
Kelvin
Vanessa
Teeterville
Windham Centre
La Salette
Atherton
Lynedoch
Silver Hill
South Middleton
Wyecombe
Courtland
Otterville
Big Creek
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Water Resources of the Big Creek Drainage Basin

WATER RESOURCES
REPORT 2

Water Resources of the Big Creek Drainage Basin

By
T.J. Yakutchik and W. Lammers

ONTARIO WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

TORONTO ONTARIO

1970

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WATER RESOURCES OF THE BIG CREEK BASIN

ABSTRACT

Drainage basin surveys are part of a water-resources inventory program conducted by the Ontario Water Resources Commission to promote the orderly management of the resource in the province. The Big Creek study was undertaken because of the demands for water for irrigation of tobacco.

Field investigations consisted of gathering pertinent geologic, hydrologic, water-quality and water-use data to support other data drawn from file.

The report presents an evaluation of ground-water and surface-water resources in terms of quantity, quality, occurrence and use. The various hydrologic parameters are examined and a hydrologic budget is presented.

Precipitation averages about 37 inches per year and is generally adequate. During extended dry periods in the summer, irrigation is practised to overcome moisture deficiencies. During the period October 1962 to September 1967 the mean annual precipitation was about four inches below normal.

Ground-water supplies are abundant in the sand deposits that cover a large part of the basin. Other supplies are also available at depth in the overburden and in the upper part of the bedrock. Ground-water runoff was calculated to amount to about seven inches annually and maintains stable base flows in the streams. The water is generally of good quality and is used extensively for domestic and irrigation purposes.

Surface-water supplies are generally abundant except during the irrigation period. During this period extensive withdrawals of water seriously deplete the streamflow; as much as 70 per cent on maximum days. Annual runoff ranged from 6.8 to 14.7 inches during the below-normal precipitation period from October 1962 to September 1967.

For the period October 1962 to September 1967 potential evapotranspiration calculated by the Thornthwaite method from data for the Delhi meteorological station was 23.7 inches, and the estimated average evapotranspiration for the basin above Delhi was 23.0 inches.

The period July 1, 1964, to June 30, 1965, was selected for the preparation of a water budget. Total precipitation for the basin during the period was calculated to be 37.9 inches; total runoff as streamflow was 15.2 inches; and the difference, deduced to be due mainly to evapotranspiration, was 22.7 inches. About 46 per cent of the runoff was probably ground-water discharge. The various values calculated for the budget period are reasonable estimates of average conditions in the Big Creek basin.

Estimated water extractions in the basin in 1964 totalled 1,070 million gallons, about 2 per cent of the average annual runoff; however, 56 per cent of the water was used for the irrigation of tobacco during July when streamflows were far below average. More intensive management of water resources in the basin is required to meet the full range of needs during periods of peak demand.

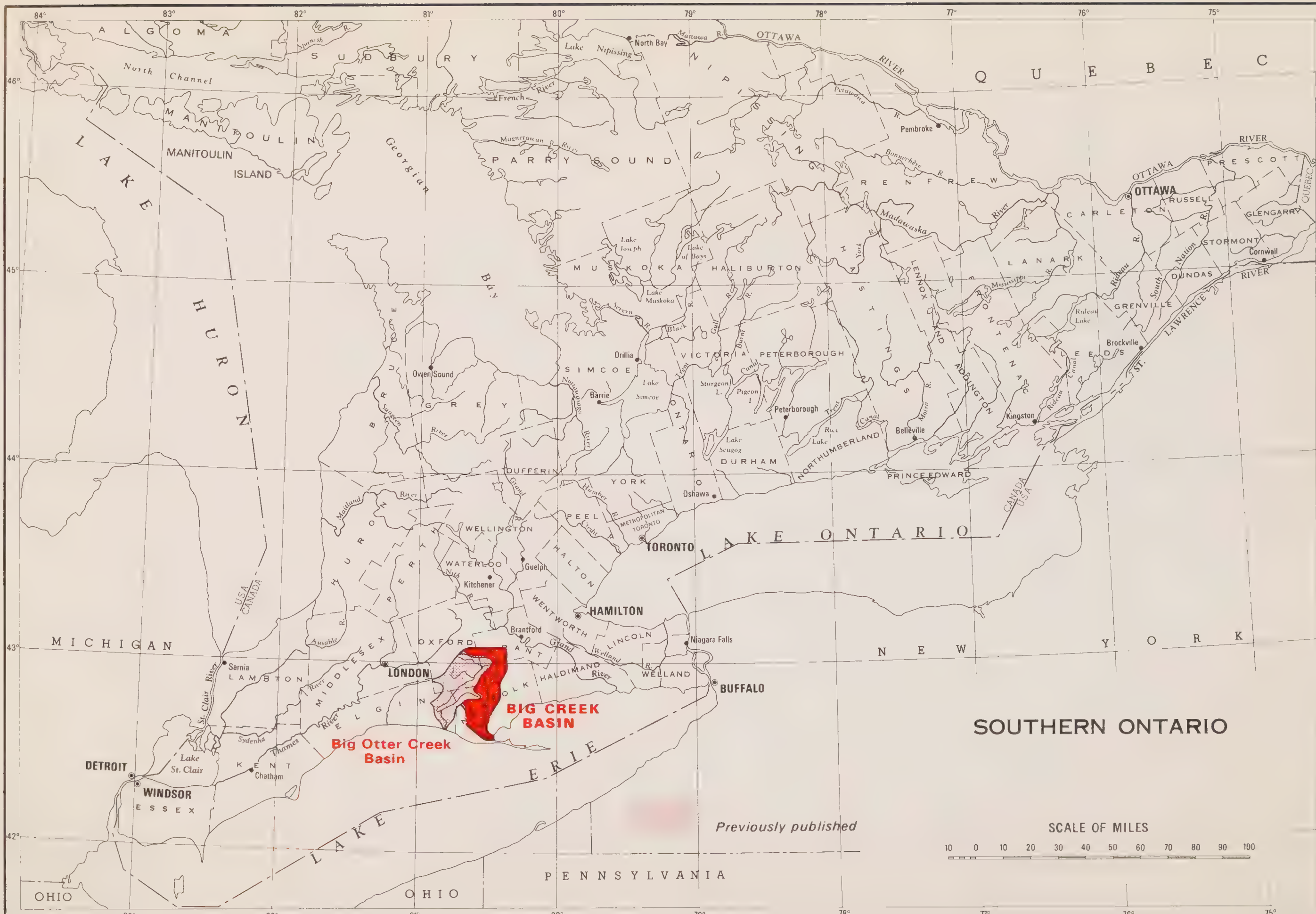


Figure 1. Location of Big Creek basin in Southern Ontario.

INTRODUCTION

Purpose and Scope of the Investigation

Drainage basin surveys are part of the program of water-resources inventory studies undertaken by the Ontario Water Resources Commission to plan for the maximum and orderly development and management of the water resources of the province. The drainage basin survey undertaken in the Big Creek basin is one of a series of such studies.

The study was initiated in 1964 and was supported financially under the Federal-Provincial Rural Development Agreement. The basin was selected for study primarily because of the demand for water for the irrigation of tobacco crops.

This report presents an evaluation of water resources in the basin in terms of quantity, quality, occurrence and present and future uses. The primary objective of the report is to provide basic resource information and guidance to individuals, groups and agencies for the development of the water resources to meet individual and collective needs.

Field work was initiated early in 1964 and completed in 1965. Investigations were made of water wells, geologic conditions, surface-water flows, ground-water levels, water quality and water uses. A test-drilling program was carried out to provide observation wells and to supplement hydrogeologic information.

Location and Extent of Basin

The Big Creek basin is located in southwestern Ontario between longitudes 80°23′ and 80°41′W, and latitudes 42°35′ and 43°05′N (Figure 1). The basin has an area of about 280 square miles, a length of about 35 miles in a north-south direction and a width which varies between 8 and 14 miles in an east-west direction.

The basin is bounded on the north by the Grand River system; on the east by several small river systems, the chief of which are the Nanticoke, Young and Dedrich creeks and the Lynn River; and on the west by the Big Otter Creek system. All of these systems drain into Lake Erie. A small area in the north-western tip borders on the Thames River system which flows into Lake St. Clair.

The headwaters of Big Creek rise in Oxford County just north of Burgessville and south of Oriel. At first the stream flows in an easterly direction and then turns south between Harley and Northfield Centre. From there it follows a southerly direction to discharge into a broad marsh at the west end of Long Point Bay, on Lake Erie.

Previous Investigations and Reports

A comprehensive report on the Big Creek drainage basin, titled "Big Creek Valley Conservation Report, 1953", was published in 1953 by the Department of Planning and Development. The report is divided into three basic parts:

Forestry, Wildlife and Ponds. In 1958, the "Big Creek Region Conservation Report" was published by the Conservation Branch under the Ontario Department of Planning and Development. It consisted of four sections: Forest, Land, Water and Wildlife. History and Summary sections of the report were published in 1963. The latter sections of the report were compiled and published by the Conservation Authorities Branch under the Ontario Department of Lands and Forests.

"Physiography of Southwestern Ontario" by Chapman and Putman (1951) describes the land forms and Pleistocene deposits found in the Big Creek drainage basin.

The Ontario Water Resources Commission has published reports on the water resources of Brant County (1964) and Norfolk County (1963). Reports on ground-water surveys for Courtland and Delhi are on file at the offices of the Commission. Two reports, "Water Sources and Irrigation Survey of the North Creek Watershed, 1955" and "1957", are also on file with the OWRC and contain information on water use in the area of the North Creek Watershed.

A soil map for the County of Oxford was published by the Ontario Department of Agriculture in 1961. A soil map for the County of Norfolk was published by the Federal Government.

Two maps by Sanford (1954) show drift-thickness and bedrock-elevation contours in Norfolk County.

Acknowledgements

The survey was carried out under the general supervision of Mr. K. E. Symons, Director, and Mr. D. N. Jeffs, Assistant Director, Division of Water Resources, Ontario Water Resources Commission. Mr. U. Sibul assisted in the assembly and preparation of hydrogeologic data and maps. Mr. B. A. Singh gathered surface-water data and prepared maps.

Technical assistance in the assembly of field and office data was provided by Messrs. R. Chajkowski, D. McCowan, J. Sanders, C. H. Yu and M. Birtles.

The figures and maps that appear in the report were prepared by Mrs. S. Impey and Miss C. Packer under the supervision of Mr. H. Flotner, Chief Cartographer.

Water analyses were made by the Chemistry Branch of the Division of Laboratories, under the supervision of Mr. C. E. Simpson.

The co-operation of the Big Creek Region Conservation Authority and the residents of the area is greatly appreciated.

Appreciation is extended to Mrs. L. Blagdon, Mrs. V. Josey, and Mrs. P. Sanderson, without whose stenographic assistance this report would not have been possible.

GEOGRAPHY

Physiography

Topography

The topography of the Big Creek basin is characterized by a broad, flat plain, interrupted sporadically by prominent ridges and deeply-incised stream valleys. The topography is a direct result of deposition and erosion during glacial and post-glacial times.

During oscillations of the continental ice sheets, morainic ridges and till plains were formed in the area. Four morainic ridges are identifiable in the basin: St. Thomas, Norwich, Tillsonburg and Paris moraines. Of these, the Tillsonburg and Paris moraines are best developed topographically. The Tillsonburg moraine is a till ridge that extends from Harley in the north past Summerville in the west. The Paris moraine is partly a till ridge and partly a kame sand and gravel ridge that extends from Fairfield Plain in the north to Delhi in the south, where it becomes hardly noticeable topographically. Topographic ridges west of Delhi may be extensions of this moraine. A till plain was developed between the St. Thomas and Norwich moraines in the extreme northwest section of the basin. The till area in the extreme southern end of the basin may be part of a buried moraine. The similar shape and parallelism of the morainic ridges are noteworthy features. The moraines exercised a great deal of control in subsequent topographic developments. Till and clay deposits occupy about 20 per cent of the basin surface and kame and outwash deposits about four per cent.

During deglaciation large quantities of meltwater from the retreating glacier carved out spillway channels between the moraines and across the moraines such as south of Harley and west of Delhi. As the glacier withdrew from the area, glacial lakes formed in the southwest and gradually rose to inundate most of the basin, except for the tops of the morainic ridges in the northern part of the basin. Large deltas formed in areas where spillway waters entered the shallow waters of the glacial lakes, and the sand plains, so characteristic of the area, were formed. Where moraines protruded above the lakes, shoreline scarps, beaches and gravel bars were formed. Sand plains occupy about 70 per cent of the surface area; beach deposits, about one per cent.

As the glacial lakes receded to the present stages of the Great Lakes, drainage patterns developed on the land surface and deep, V-shaped stream valleys were eroded. Several different levels of stream terraces along the Big Creek channel between Delhi and Lake Erie probably reflect, in large part, changing drainage conditions in the basin during post-glacial times. Isostatic rebound of the earth's crust increased the land surface gradient in a southwest direction with the result that stream velocities, and thereby erosion action, were increased until the present conditions were reached. Swamps and bogs developed in northern areas where drainage was poor. Flood plains, swamps and bogs occupy about 5 per cent of the basin.

Areal distribution of the various surficial deposits is shown in Table 1.

Table 1. Areal Distribution of Surfical Deposits, Big Creek Basin

Basin or Sub-Basin	SURFICIAL DEPOSITS												
	Area	Sand		Till and Clay		Beach S&G		Outwash and Kame S&G		Swamp		Alluvium	
	Mi^2	Mi^2	%	Mi^2	%	Mi^2	%	Mi^2	%	Mi^2	%	Mi^2	%
Above Kelvin Gauge	53	25	47	25	47	0	0	1	2	2	4	0	0
Kelvin to Delhi Gauge	89	57	65	16	18	2	0	10	11	2	2	2	2
Above Delhi Gauge	142	82	59	41	29	2	1	11	8	4	2	2	1
Delhi to Walsingham Gauge	79	68	87	7	9	0	0	1	1	0	0	3	3
Above Walsingham Gauge	221	150	68	48	22	2	1	12	5	4	2	5	2
Above Venison Gauge	34	31	88	2	6	1	3	0	0	0	0	1	3
Walsingham to Lake Erie	24	14	58	8	33	0	0	0	0	0	0	2	9
Total Basin	280	195	70	58	20	3	1	12	4	4	2	8	3

Land surface elevations vary from 572 feet at Lake Erie to about 1,100 feet above sea level in the extreme northwest corner of the basin. The land surface gradient near Lake Erie is about 50 feet per mile but reduces rapidly northward and is about eight feet per mile near Delhi. Above Delhi, the gradient is about five feet per mile to New Durham. On the moraine areas changes in relief are very abrupt with slopes varying from gentle to very steep.

Drainage

Drainage in the basin is through Big Creek and its tributaries. The streams have their headwaters on the moraine ridges but are primarily located on the plain areas between the moraines, except where the moraines have been gapped. In the southern part of the basin the streams flow in deep V-shaped valleys. Gradients along Big Creek vary from a few feet per mile south of Walsingham to about ten feet per mile near Delhi. Gradients decrease above Delhi to about five feet per mile near Harley and then increase west of Harley. In tributaries, gradients are generally fairly steep.

Climate

The drainage basin lies in the most southerly part of Canada and possesses a temperate climate that receives a moderating influence from the nearby Great Lakes system. As a result, the area enjoys long frost-free intervals and abundant precipitation that is fairly well distributed throughout the year.

Temperature

The average annual temperature, as recorded at the Delhi meteorological station, is 46.6°F. The lowest monthly average temperature of 23.1°F occurs in January, and the highest monthly average of 70.1°F in July. A summary of the average monthly and annual temperatures at Delhi, based on the period 1935 to 1960, is as follows:

Month	Temperature (°F)
January	23.1
February	23.8
March	31.9
April	44.0
May	55.1
June	65.6
July	70.1
August	68.4
September	60.9
October	50.4
November	38.3
December	27.1
Annual	46.6

The mean May temperature is above 55°F nearly everywhere in the basin, and an average of about 200 hours of sunshine is recorded at the Delhi station. Late spring frost ends in the early days of May. These factors combine to give

agriculture an early start and a stimulating early growing period. The growing season is unrestricted by freezing temperatures for an average of 160 days. The average monthly May to September sunshine hours is above 200 hours.

Precipitation

The precipitation varies over the basin with the Delhi station recording an average annual precipitation of 37.66 inches, which is equivalent to a monthly average of 3.14 inches for the period 1935 to 1960. These average data for the Delhi station may be considered representative of the region. The total annual precipitation may, however, vary greatly from year to year. Three of the driest years on record occurred during eight years prior to 1964. The lowest recorded annual precipitation of 23.7 inches occurred in 1963. Average monthly and annual precipitation at Delhi is summarized below:

Month	Precipitation (inches)
January	3.07
February	3.09
March	3.18
April	3.59
May	3.36
June	2.92
July	3.05
August	3.15
September	3.21
October	2.92
November	3.02
December	3.10
Annual	37.66

Detailed discussion of the precipitation is presented under the hydrology section of this report.

Population

The population of the basin in 1964 was about 15,730. The 1964 population by county is as follows:

Brant	–	1,590
Norfolk	–	12,960
Oxford	–	1,180
Total		15,730

The Town of Delhi, population 3,625 (Ontario Department of Municipal Affairs, 1964), is the largest concentration of population and is located near the centre of the basin. The remainder of the population is primarily rural but a certain portion is located in small communities such as Walsingham, Langton, Lynedock, La Salette, Teeterville, Kelvin and Harley.

Because of the agriculturally-orientated economy of the area and the relatively constant density of farms, the population growth has been slow. A change in the trend may come about with the development of the Haldimand-Norfolk region. During tobacco harvesting, the area experiences a temporary increase in the population because of transient workers.

Land Use

The Big Creek drainage basin contains about 280 square miles of territory and contains portions of the counties shown below:

County	Area Within Basin (square miles)	Percentage of Total Basin
Brant	41.4	14.7
Norfolk	207.4	74.0
Oxford	31.6	11.3
Totals	280.4	100.00

The basin contains portions of the following municipalities:

Municipality	Area Within Basin (square miles)	Percentage of Total Basin
Twp. of Burford	41.4	14.8
Twp. of Charlotteville	16.8	6.0
Town of Delhi	1.2	0.4
Twp. of Houghton	2.0	0.7
Twp. of Middleton	34.9	12.5
Twp. of Norwich North	7.9	2.8
Twp. of Norwich South	13.8	4.9
Twp. of Oxford East	9.9	3.5
Twp. of Walsingham North	59.2	21.1
Twp. of Walsingham South	26.7	9.5
Twp. of Windham	66.6	23.8
	280.4	100.0

The economy of the Big Creek basin is essentially agriculturally based. Table 2 shows the land use, and Table 3, the crop distribution within the basin for 1966. The Dominion Bureau of Statistics (DBS), 1966 data, were used in the compilation of these data. Data on the tobacco crop in Table 3 were derived from information received from the Ontario Flue-Cured Tobacco Growers' Marketing Board. Tobacco was the major crop grown in 1966.

Table 2. Land Use, Big Creek Basin, 1966

(All values in acres)

County	Total Area	Improved Farm Lands*	Unimproved Farm Lands	Other
Brant	26,500	18,300	5,000	3,200
Norfolk	132,800	86,200	29,000	17,600
Oxford	20,200	16,000	2,600	1,600
Total	179,500	120,500	36,600	22,400

* After Dominion Bureau of Statistics, 1966

Table 3. Crop Distribution, Big Creek Basin, 1966

(All values in acres, after Dominion Bureau of Statistics, 1966)

County	Total Crops	Tobacco	Corn for Grain	Wheat	Rye	Other
Brant	14,600	3,500	2,500	900	1,400	6,300
Norfolk	66,100	22,700	9,800	11,400	8,800	13,400
Oxford	12,700	1,800	2,300	700	800	7,100
Total	93,400	28,000	14,600	13,000	11,000	26,800

* After Ontario Flue-Cured Tobacco Growers' Marketing Board

The land use pattern for 1966 (Table 2) is considered to represent that of 1964 satisfactorily. The crop distribution is stable from year to year except for tobacco and its rotation crops, mainly rye and wheat. The tobacco acreage can vary widely from year to year due to the regulatory function of the Ontario Flue-Cured Tobacco Growers' Marketing Board which sets yearly, compulsory, maximum limits on the basis of the Basic Marketing Acreage (BMA).

The table below lists the Flue-Cured Tobacco Acreages allocated and actually planted in Ontario annually as a percentage of the BMA:

Year	Basic Marketing Acreage allocated (%)	Basic Marketing Acreage planted (%)
1958	87.5	82.3
1959	78.9	74.6
1960	87.5	82.5
1961	83.5	80.8
1962	79.4	76.6
1963	67.1	65.3
1964	49.9	48.3
1965	59.0	57.0
1966	84.1	77.0
1967	91.0	84.0
1968	83.1	80.1

In the sand plain region in southern Ontario, of which Big Creek basin is a part, harvested acreages have increased 17-fold, yield per acre has doubled, and total production of tobacco has thus increased 34-fold since 1924. Much of this increase in yield is due to improved cropping and curing methods, use of insecticides and fertilizers and sprinkler-irrigation practices.

The Big Creek basin produces about one-fifth of the flue-cured tobacco grown in the province. The total BMA is estimated to be 36,400 acres and represents about 23.9% of the Ontario total.

The estimated tobacco acreages planted in the basin annually are as follows:

Year	Acres Planted	% BMA	% of Total Crop Acreage*
1958	30,000	82.3	32.1
1959	27,200	74.6	29.1
1960	30,000	82.5	32.1
1961	29,400	80.8	31.5
1962	27,900	76.6	29.9
1963	23,800	65.3	25.5
1964	17,600	48.3	18.8
1965	20,700	57.0	22.2
1966	28,000	77.0	30.0
1967	30,600	84.0	32.8
1968	29,200	80.1	31.3

*Total crop acreage based on 1966 DBS census data.

Other crops, in addition to those listed in Table 3, in order of acreage are: hay, 9.2%; oats, 7.3%; corn for ensilage, 2.8%; barley, 1.9%; potatoes and mixed grains, 0.9% each.

On the heavier soils in the basin, dairy farming is of greater importance. Table 4 is a tabulation of the distribution of estimated livestock in the basin. In areas of poor soil drainage, such as in the silt till, attempts have been made to improve the drainage by tiling the fields. Municipal drains and ditches have been widely developed to improve many existing water courses (Map 2706-8).

Table 4. Livestock Distribution, Big Creek Basin, 1966

(After Dominion Bureau of Statistics, 1966)

County	Dairy Cattle	Other Cattle	Hogs	Sheep	Horses	Chickens
Brant	1,220	1,410	2,580	130	120	16,860
Norfolk	970	3,830	5,010	130	780	179,520
Oxford	1,670	2,160	3,100	50	50	25,820
Total	3,860	7,400	10,690	310	950	222,200

Managed woodlots account for about 13 per cent of the census-farm areas. Other woodlots are owned and/or managed by private individuals, municipalities, the County of Norfolk, the Big Creek Conservation Authority, and the Department of Lands and Forests. Many woodlands and poorly-drained areas are maintained in an effort to prevent stripping of land and to preserve and promote fish and wildlife conservation in the basin.

GEOLOGY

The occurrence, availability and quality of water in an area, whether from surface- or ground-water sources, are in part dependent on the composition, distribution and hydraulic properties of the subsurface formations. An understanding of the geology is therefore essential to any water-resources survey.

For the purposes of this survey, the geology was interpreted from field examinations of the geologic deposits and land forms, complemented by the work of previous investigations, Chapman and Putnam (1951), Dreimanis (1951), Karrow (1963), Sanford (1958) and Watt (1949).

The significant geologic units in the Big Creek basin are discussed below under two main headings — Bedrock Geology and Surficial Geology. Bedrock is a term used to refer to the consolidated or solid rock formations of the earth's crust. Surficial is a term used to refer to the overburden or the unconsolidated, granular, rock materials that mantle the bedrock surface and form the deposits at the surface of the ground. The distribution of the geologic units is shown on maps 2706-2 and 2706-3. A summary of the geologic units and their position in the stratigraphic column is given in Table 5. Generalized cross-sections of the geology in the basin are shown in figures 2 and 3.

Bedrock Geology

Description and Distribution

The consolidated bedrock formations in the Big Creek basin consist of Paleozoic sedimentary rocks of Upper Silurian and Middle Devonian age. The formations are entirely obscured by overlying surficial deposits. The location of the formations at the bedrock surface, that is, where they subcrop beneath the overburden, is shown on Map 2706-2. The distribution is based mainly on previous geologic reports and maps. Sanford (1958), with some modifications based on lithologic logs obtained during more recent drilling. A stratigraphic succession of the formations is presented in Table 5 and illustrated in Figure 2.

The Salina Formation is the oldest sedimentary rock unit and occurs in the extreme northeastern region of the basin. It consists of buff to brown dolomite and limestone with grey shales and gypsum and anhydrite deposits in some localities in the province. It may reach a thickness of 380 feet within the area of the basin.

The Bass Island Formation overlies the Salina Formation and subcrops as a narrow band through Burford Township. It consists of cream and buff dolomite and may be up to 75 feet thick in sections of the basin. The Bass Island Formation marks the top of the Silurian rock formations.

Overlying the Bass Island Formation in some localities but not shown in the stratigraphic column is the Oriskany Sandstone. Difficulty in mapping the unit led to its omission. Occurring as it does at the base of the Devonian rock system and at a disconformity between two rock systems, might, however, make the formation an important hydrogeologic unit. This will be discussed further under Hydrology.

Table 5. Stratigraphic Column of the Geologic Units in the Big Creek Basin

ERA	PERIOD	EPOCH	FORMATION	CHARACTER OF MATERIAL	MAXIMUM THICKNESS (feet)
Cenozoic	Quaternary	Recent	Eolian and Alluvium	Stratified sand and silt, a few pebbles	20
			Swamp or marsh	Mainly organic matter, some silt	—
		Pleistocene	Wisconsinan Glacial Drift	Stratified deposits of clay, silt, sand and gravels of lake, stream spillway, deltaic and glacial outwash origin. Unstratified deposits of till, an unsorted mixture of clay, silt, sand, gravel and boulders in varying proportions, of glacial origin.	325
Paleozoic	Devonian	Middle Devonian	Delaware	Brown and buff limestone, some chert	120
			Detroit R.	Brown and buff limestone and dolomite; sandstone	50
			Bois Blanc	Limestone, dolomite and chert; sandstone	150
	Silurian	Upper Silurian	Bass Is.	Cream and buff dolomite	75
			Salina	Buff to brown dolomite and limestone; grey dolomitic shale	380

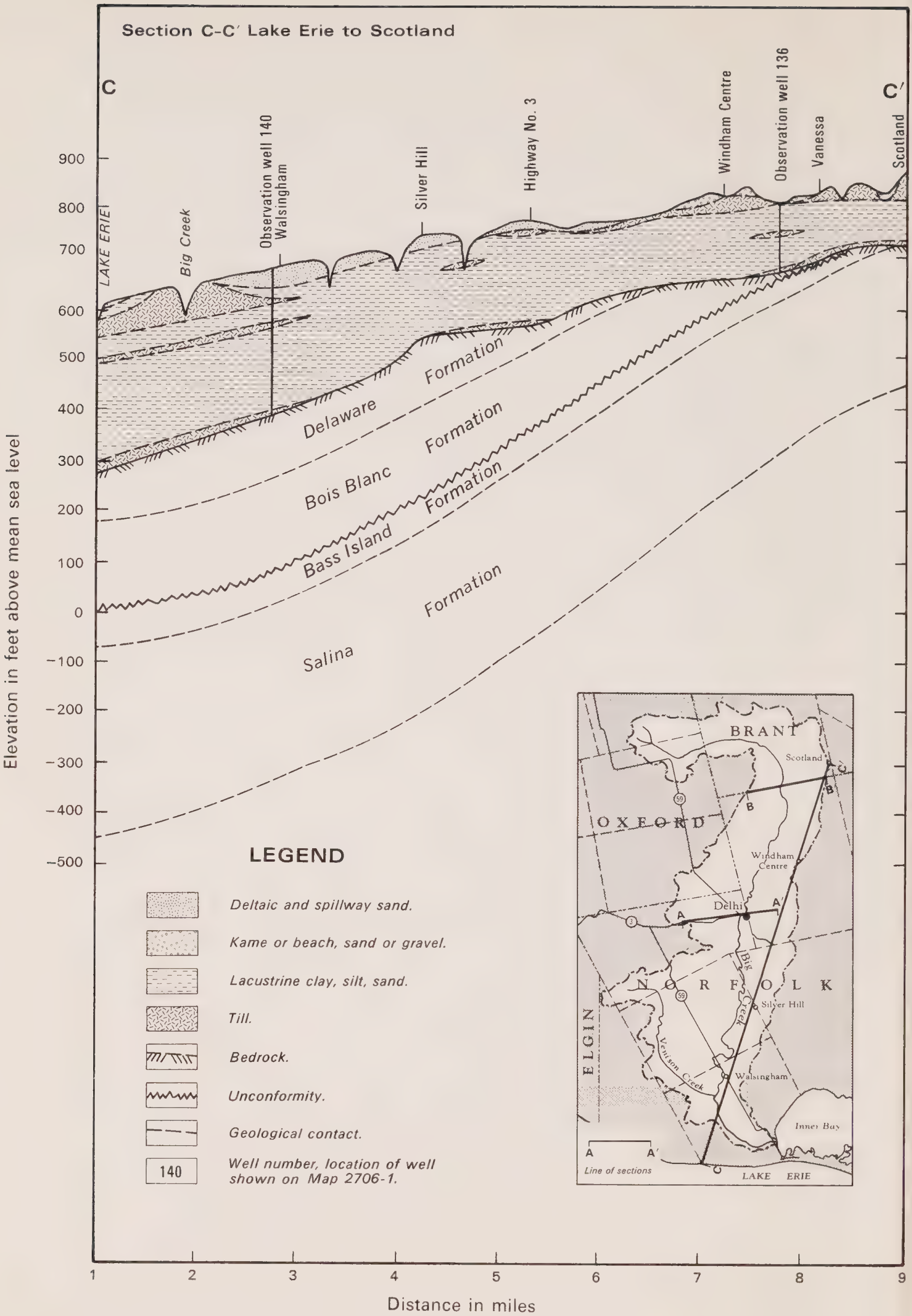


Figure 2. Generalized geological cross-section of bedrock and overburden formations from Lake Erie to Scotland.

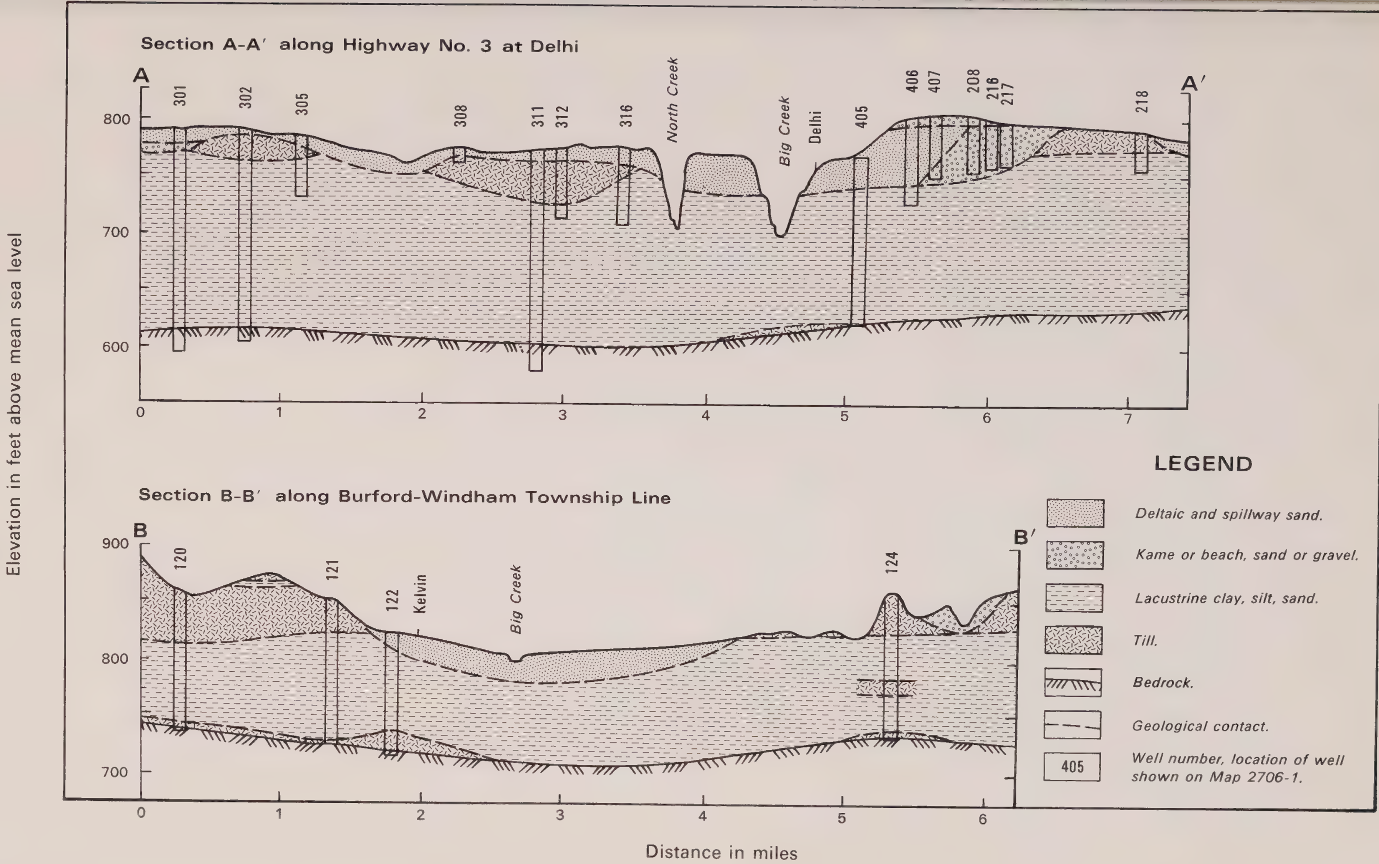


Figure 3. Generalized geological cross-sections of overburden formations along Highway No. 3 at Delhi and along Burford-Windham township line.

Excepting the Oriskany Formation, the Bois Blanc Formation is generally considered as the bottom marker bed of the Devonian rock system and lies disconformably on the Bass Island Formation. It consists of limestone, dolomite and chert and occurs as a band four to seven miles wide through the north-central region of the basin.

The Bois Blanc Formation grades upward to brown and buff limestone and dolomite of the Detroit River Group of formations. A biohermal reef development is believed to be present in the lower part of the group. The group occurs in the Burgessville area of North Norwich Township. The location of these formations, as shown in G. S. C. Map 1062A, was modified on the basis of more recent drill hole logs. The Detroit River formations are shown as being absent in Windham Township due to pinch-out. More recent thinking suggests that the formations do occur in this area. (Personal communication — R. Beards, Ontario Department of Energy and Resources Management.)

The Delaware Formation consists of brown and buff limestone with some chert and is the youngest sedimentary rock unit in the basin. It comprises about three-quarters of the bedrock surface.

Structure and Topography

The bedrock underlying the Big Creek basin derives its structure from the regional structure of the bedrock throughout the southern part of the province. Being situated on the southern flank of the Algonquin Arch, the formations dip to the south or southwest at about 25 to 30 feet per mile. A disconformity or eroded surface is reported to separate the Devonian and Silurian strata and may be of importance from a hydrogeologic point of view.

The topography of the bedrock surface can be interpreted readily from the elevation contours shown in Map 2706-2. For the most part, the surface can be described as being flat to undulating. It slopes southward at a gradient of about 10 to 25 feet per mile (Figure 2). Where data are more plentiful, a somewhat more irregular surface is indicated, but there is little evidence of any significant channels or valleys in the surface. Contours in the vicinity of Harley in Burford Township indicate a northward continuation of the Onondaga Escarpment which traverses a broad section of the province. Data are scant but there is an indication that the escarpment was gapped by a channel in the Fairfield Plain area.

Surficial Geology

Description and Distribution

The overburden or unconsolidated deposits in the Big Creek basin consist mainly of glacial drift of Pleistocene age with minor amounts of alluvial, swamp and eolian deposits of Recent age. The term "glacial drift" refers to all deposits of glacial origin, both stratified and unstratified. Unstratified or morainic deposits consist mainly of till whereas stratified deposits include glacial outwash or kame sand and gravel, lacustrine clay, silt and fine sand and fluvial or shallow-water lascustrine (spillway and deltaic) sands and gravels.

The location or distribution of the deposits at the land surface is shown on Map 2706-3. The distribution is based mainly on geologic mapping carried out during the summer of 1964, with reference to previous geologic reports and maps, A. K. Watt (1949, unpublished), Chapman and Putnam (1951). The position of the deposits in the stratigraphic succession is presented in Table 5.

Generalized cross-sections of the overburden are illustrated in Figure 2 and Figure 3.

The thickness of the overburden is shown on Map 2706-4 by means of isopachs or lines of equal thickness. The overburden generally thickens southward from a minimum of 25 feet near Harley to a maximum of 325 feet near Lake Erie. In northern sections, the greatest thicknesses occur along the morainic ridges. South of Delhi, the thickness increases gradually toward Lake Erie, except where deep dissection by Big Creek and its tributaries has altered the pattern.

Morainic Deposits

These deposits consist mainly of till, an unsorted mixture of gravel, sand, silt and clay in varying proportions, but may contain minor amounts of sorted and stratified material locally. Four till units were observed in the basin; two in surface exposures and two in drill hole cuttings. The tills are present in the form of end moraine along the morainic ridges and as ground moraine in areas between the ridges, and at depth in the overburden.

The tills in the basin are probably the result of deposition during the Wisconsinan ice age and vary in composition from silty clay to silty sand. In all instances, the tills are separated by stratified deposits of clay, silt or sand.

The lower-most and probably the oldest till observed is one that overlies the bedrock surface. Drill-hole cuttings and logs suggest that the till is ablation in nature and variable in composition and distribution. A thickness of 15 feet of stony clay till was penetrated in a hole near Walsingham at a depth of 281 to 296 feet. Other drill-hole logs indicate it is absent in many areas. Occasionally, a heterogeneous sand and gravel deposit is encountered at the bedrock surface and may, in fact, be a remnant of the till.

The second lowest till observed in the basin was in a drill hole near Walsingham. A silty clay till was penetrated between 106 and 113 feet. Correlation to other tills in the area was not possible. Distribution appears to be limited to the southern part of the basin.

The third lowest till, clayey in composition, outcrops in abundance in the extreme southern end of the basin. It appears to be present in the form of an east-west trending end moraine, the north and south slopes of which are buried by lacustrine or spillway deposits. Drill-hole logs indicate the moraine may be up to 70 feet thick and thins to the north and south. Northward toward Delhi, several outcrops of clay till were observed at low elevations along deep stream dissections and may correlate to this till. Three feet of clay till, penetrated at a depth of 64 to 67 feet near Vanessa, may also correlate with the till moraine. A lower till exposed along the Tillsonburg moraine is of a similar composition.

The uppermost till in the area occurs along the morainic ridges. It is primarily silty or sandy in composition with an abundance of coarser fragments in the northern areas. Thicknesses are highly variable along the rugged ridges but may exceed 50 feet in some locations.

End moraines are significant topographic features in the basin and, through their concave shapes and parallel northeast-southwest trends, indicate pauses or halts in a retreating ice lobe. Four are present: the St. Thomas and Norwich moraines in the extreme northwest lobe of the basin, the Tillsonburg moraine along the western boundary, and the Paris moraine along the eastern boundary and apparently traversing the basin west to southwest of Delhi. A fifth, buried moraine apparently crosses the basin near its mouth. Although depositional in nature, the morainic ridges owe much of their relief to erosion by meltwater. Exposed stratified deposits in the ridges and sculptured shapes

suggest that strong fluvial currents from the north accentuated the ridges by down-cutting between the moraines, particularly the Norwich and Tillsonburg moraines and the Tillsonburg and Paris moraines. Although some erosion took place between the St. Thomas and Norwich moraines, its effects are only vaguely noticeable in the form of a bevelled till plain. The currents apparently produced prominent breaks in the Tillsonburg moraine near Harley in Burford Township and in the Paris moraine near Delhi in Middleton Township.

Lacustrine Deposits

Lacustrine deposits is a term used to describe the very fine-grained, well-sorted and well-stratified materials that owe their origin to deposition in ponded water of varying depth. These deposits may constitute over 75 per cent of the overburden in many parts of the basin and typically consist of alternating beds of clays, silts and very fine sands in a variety of thicknesses and combinations.

A detailed examination of the deposits was not carried out, but field data suggest that several sequences may be present. This is particularly true where deposits form a distinct separation between the various till deposits. Outcrops of the deposits are in abundance along the deeply-dissected stream channels below Delhi. Sections in excess of 50 feet in thickness are common and their occurrence directly below surficial sands and above or below till deposits clearly visible. Well-stratified, fine sand layers separate two tills in the Tillsonburg moraine in Burford Township. South of Delhi, the top of the uppermost lascustrine sequence shows abundant distortions, indicating an over-riding by glacial ice.

Shallow-Water Lacustrine and Fluvial Deposits

This term is used to describe the sand deposits that occur at the surface of the ground in the broad, flat areas of the basin, commonly referred to as the Norfolk sand plain (Chapman and Putnam, 1951). The deposits typically consist of fine to medium sand but may vary locally to coarse sizes. Gravels are present in the area south of Burford. The deposits owe their origin to deposition in meltwater channels and in shallow ponded water, and consequently, are characterized by good to poor sorting and good to poor cross-bedding. The thicknesses of the deposits are variable, depending on their location in the spillway channels. However, depths of 20 to 30 feet are common over much of the area, except where erosion by wind or water has altered the pattern. Northeast of Walsingham, depths of up to 50 feet were observed in exposures and reported on well logs. Subsequent inundation of the area by glacial lakes probably resulted in a further bevelling of the sand plain and deposition of a thin veneer of sand over portions of the moraines.

Beach Deposits

As meltwaters entered the area from the north, lakes or ponds formed in the south and lake levels gradually rose and inundation by glacial lakes Arkona, Whittlesey and Warren resulted. The lakes left their marks in the form of wave-cut beach lines and sand and gravel bars. Wave-cut beach lines with or without associated beach deposits are abundant along the morainic ridges, especially the St. Thomas moraine in East Oxford Township and the Tillsonburg and Paris moraines in Windham Township. Sand and gravel bars, formed in the glacial lakes, are prominent along the Paris moraine east and northeast of Delhi. Other beach deposits are present along what is probably a continuation of the Paris moraine in Middleton Township. Dune ridges throughout the

southern part of the basin are probably fore-shore deposits that mark former beach lines.

Kame and Glacial Outwash Deposits

As glaciers melt, the meltwater picks up and carries sediment to the ice front and may deposit the material at or near the ice front in the form of hills or fans. Characteristically, the deposits consist of sand and gravel, and may be well to poorly sorted and well to poorly stratified. Lenticular cross-bedding is typical. The deposits are present in abundance along the Paris moraine. The thickness of the deposits is highly variable but may exceed 25 feet in some areas.

Alluvial Deposits

Alluvial material consisting mainly of sand, is found primarily along flood plains of Big Creek south of Delhi. The deposits are usually thin but may reach 20 feet in some areas.

Swamp Deposits

Bogs and swamp are common in the flat, poorly drained areas of the basin. Many of the swamps are covered with dense forest and contain varying thicknesses of peat, muck and silt.

History of the Pleistocene Deposits

The Pleistocene history of the area is complex. Although it was not the intention of this survey to unravel the sequence of events that took place, some interpretation became inevitable in order to understand the occurrence and distribution of the unconsolidated deposits and their water-bearing characteristics.

The overburden in the basin is mainly Pleistocene in age and is the result of deposition and erosion by continental glaciers that advanced and retreated at least four times during the epoch. No evidence was found to indicate that any of the Pleistocene deposits were deposited at any time other than during the last glacial, or Wisconsinan stage.

Field evidence shows that at least three, or possibly four tills are present in the area. Tills show the general behavioural pattern of the ice sheets and, from the tills present, it can be assumed that the ice lobes made three major advances and retreats through the area. The second oldest till may only be the result of local activity. Details of early glacial activity are sparse because of the sporadic data available. Greater detail is available on later glacial activity because of the abundance of data obtainable from surface deposits.

Two tills, deep in the overburden, indicate two early ice advances through the area. Following their retreat, meltwater inundated the area and thick deposits of clays, silts and fine sands were laid down. The later of the two tills appears to occur only in the southern part of the basin and may represent a local fluctuation in a nearby ice lobe rather than a major advance. This till was subsequently covered by lacustrine deposits.

Later glacial activity consisted of the forming of the St. Thomas and Norwich moraines in succession by a retreating ice lobe. A lower till, exposed in the Tillsonburg moraine, may have been formed by the same retreating ice sheet with the ice possibly withdrawing to or beyond the Galt moraine at Simcoe. The till, exposed at surface in the extreme southern part of the basin appears to form a buried end moraine and may have been built during this ice

activity. Subsurface data suggest that the moraine may extend to the Galt moraine at Simcoe. During the retreat of this ice, meltwater ponded in front of the ice and lacustrine silts and clays deposited over the lower till at the Tillsonburg moraine and the end moraine in the southern part of the basin.

Subsequently, the ice lobe re-advanced to the Tillsonburg moraine, overriding and incorporating lake sediments into the ice. Contortions, visible in the upper parts of these lake sediments south of Delhi, attest to the ice re-advance. As the ice then retreated from the basin it made pauses, formed the Paris moraine and deposited extensive kame and outwash sands and gravels along the moraine.

Close field investigation indicates that, within the basin, the Paris moraine consists of two separate ridges that tend to converge near Scotland and diverge southward. Topographic and geologic evidence in Middleton Township suggests that the twin strands of the moraine continue west and southwestward from Delhi into the Big Otter Creek basin. Buried fluvial deposits in front of the moraines support this theory.

As the last ice lobe retreated, meltwater from the ice, from both local and more distant areas to the north, eroded large spillway channels in front of the Tillsonburg and Paris moraines and deposited granular materials into ponded water or glacial lakes in the south. Lake levels gradually rose and eventually fell, leaving behind raised shorelines to attest to the presence of the former lakes. Shoreline features are in evidence along the St. Thomas and Tillsonburg moraines, with the one along the Tillsonburg moraine probably representing the highest lake stage of Lake Whittlesey. Parts of the Paris moraine probably protruded as islands in the glacial lakes, where wave action formed sand and gravel bars. In time, the levels of the glacial lakes lowered through several stages until the present Lake Erie and the drainage pattern in the Big Creek basin were formed.

HYDROLOGY

Introduction

The essence of a drainage basin water-resources survey is the study of the origin, occurrence and movement of water within the basin with respect to quantity, quality and time. This basically involves the science of hydrology which formally includes the circulation of water in the earth's atmosphere, on the surface of the land and in the crust of the earth. In more common terms, this circulation of water is known as the "hydrologic cycle". The objective of this section is to examine and evaluate the various components of the cycle as they pertain to the hydrologic conditions in the basin.

The principal components of the hydrologic cycle are:

(1) evaporation from the oceans and evapotranspiration from land areas;

(2) transportation, condensation and precipitation of the water vapour;

(3) return of part of the precipitation on the land to the ocean as streamflow and as subsurface discharge.

Air masses move water vapor inland from the oceans, are supplemented by additional vapor from land areas and eventually deposit the water vapor as precipitation on the land surface. Some of the precipitation is evaporated or transpired back into the atmosphere, some infiltrates into the ground and the remainder runs off overland to streams.

Part of the water that infiltrates into the ground may be retained near the surface as soil moisture or move laterally as interflow above the water-table; the remainder percolates down to the water-table to increase ground-water storage in the saturated zone, only to be eventually released as discharge to lakes and streams and through transpiration of vegetation.

Water that does not infiltrate into the ground runs off to streams, ponds and lakes and eventually to the oceans, with evaporation taking place throughout the entire interval.

From the fore-going it is obvious that the components are closely interdependent and a study of the components in detail becomes necessary if the water resources of an area are to be understood fully.

In the following paragraphs, four components — precipitation, streamflow, ground water and evapotranspiration — are discussed in detail. Long-range data were available and analyzed on precipitation and streamflow. Data on ground water, levels and discharges were available for the period July, 1964, to July, 1965, and analyses cover only this period. Evapotranspiration data were not available and values were calculated by standard methods for the period of inventory. The four components are summarized in a hydrologic budget.

Precipitation

Precipitation in the form of rain, snow, hail, frost and dew is the source of all water in the basin. It is measured at meteorological stations where the precipitation is collected in precipitation gauges. Several types are in use in southern Ontario; they consist of receptacles, generally can-shaped, which are

placed on the ground. Special snow gauges are in operation at first order meteorological stations such as at Delhi and Simcoe where the collected snowfall is melted down and its water equivalent recorded; however, at ordinary meteorological stations, snowfall is measured with a ruler at a number of representative points and its water equivalent estimated by dividing the depth by ten.

The following table lists the meteorological stations from which precipitation data for selected time periods were used in analyses in this report:

Meteorological Station	30-Year Normal (1931 - 1960)	October 1962 to September 1967	May 1964 to November 1964
Brantford	x	x	-
Cathcart	-	-	x
Clear Creek	-	-	x
Delhi CDA	x	x	x
Oxford Centre	-	-	x
Simcoe	x	x	-
St. Williams	-	x	x
Tilsonburg OWRC	-	x	x
Vanessa	-	-	x
Woodstock	x	x	-
Wyecombe	-	-	x

The precipitation data available, their consistency in comparison to regional data, and the intended use in the water resource study determine the selection of the data to be used and analyzed. The data used consisted of total daily, monthly and annual precipitation records; the methods used in their presentation and analyses are described in the following sections.

Unlike streamflow measurements, precipitation measurements are point measurements in the basin or study area and they may not be representative of basin precipitation, especially when precipitation is caused by localized thunder storms; however, all records of precipitation gauging stations used were assumed to be representative. To derive basin precipitation estimates, the Thiessen polygon method was used. Unless there is a very dense precipitation network, these estimates are likely inferior in quality to the streamflow measurements which represent the total flow generated in the tributary drainage area above the streamflow gauging location.

The representativeness of the estimated sub-basin precipitation based on the coarse network of long-term precipitation stations were compared to the estimated sub-basin precipitation using a denser network consisting of long-term and short-term stations.

Accuracy of Records

Two types of precipitation data are available: the ones published in the Monthly Record, Meteorological Branch, Canada Department of Transport, and those collected by members of the Norfolk Soil and Crop Improvement Association during the period May, 1964 to November, 1964. All precipitation records were given the same weight as far as accuracy is concerned and no distinction was made as to the type of gauge in which the data were collected.

The long-term precipitation stations were checked for consistency by means of a double-mass curve technique in which the cumulative precipitation of each station was compared to a regionalized pattern of cumulative precipitation. This pattern was composed of the mean precipitation values of five stations situated inside and outside of the basin. The consistency of the data was satisfactory for the intended use.

Annual Variation of Precipitation

The precipitation distribution at a location varies within each year primarily due to seasonal climatic factors, but, it varies also from year to year. The following presentations show the annual variability for the meteorological station near Delhi, which on Map 2706-7 is labelled North Creek, by means of histograms, frequency curves and a residual-mass curve. Figure 4 shows the histograms of the total annual precipitation and of the total June-August precipitation for the period 1935-1967, Figure 5 shows the frequency curve of the annual precipitation and Figure 7 the one for the June to August period. A residual-mass curve of the annual precipitation is presented for the same period in Figure 6.

Each of the precipitation values for the period 1954 to 1967, as shown in figures 5 and 7, is labelled with the year of occurrence for ease of comparison with available streamflow data. The sample data presented in Figure 5 indicate that they fit the normal distribution very well. The following information on annual precipitation was extracted from this figure:

Average Recurrence Interval (years)	Probability of Occurrence (per cent)	Annual Precipitation (inches)	
		will be less than	will be larger than
2	50	37.0	37.0
5	20	31.8	44.3
10	10	29.0	45.1
20	5	26.8	47.1

The sample data presented in Figure 7 indicate that the precipitation distribution was skewed. The following information on the total June to August precipitation was extracted from this figure:

Average Recurrence Interval (years)	Probability of Occurrence (per cent)	June to August Precipitation (inches)	
		will be less than	will be larger than
2	50	9.1	9.1
5	20	7.4	11.2
10	10	6.7	12.4
20	5	6.1	13.5

The residual-mass curve of annual precipitation shows the cycles of above-normal and below-normal precipitation. Figure 6 shows that the period from 1949 to 1957 was one of general above-normal precipitation and that the period from 1958 to 1964 was one of general below-normal precipitation. This is indicated by the positive and negative slopes of the residual-mass curve.

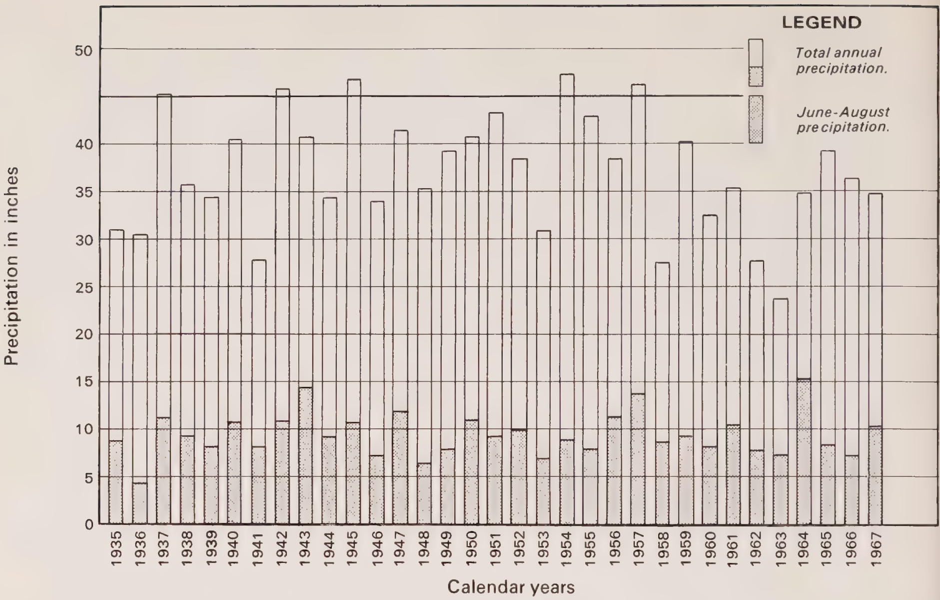


Figure 4. Histogram of annual and June-August precipitation at Delhi, 1935-1967.

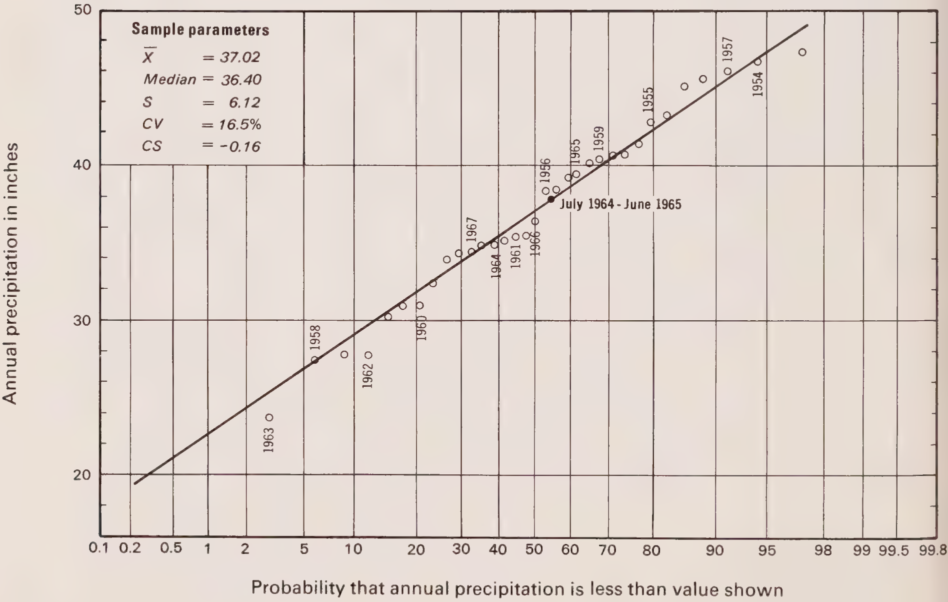


Figure 5. Frequency curve of annual precipitation, Delhi, 1935-1967.

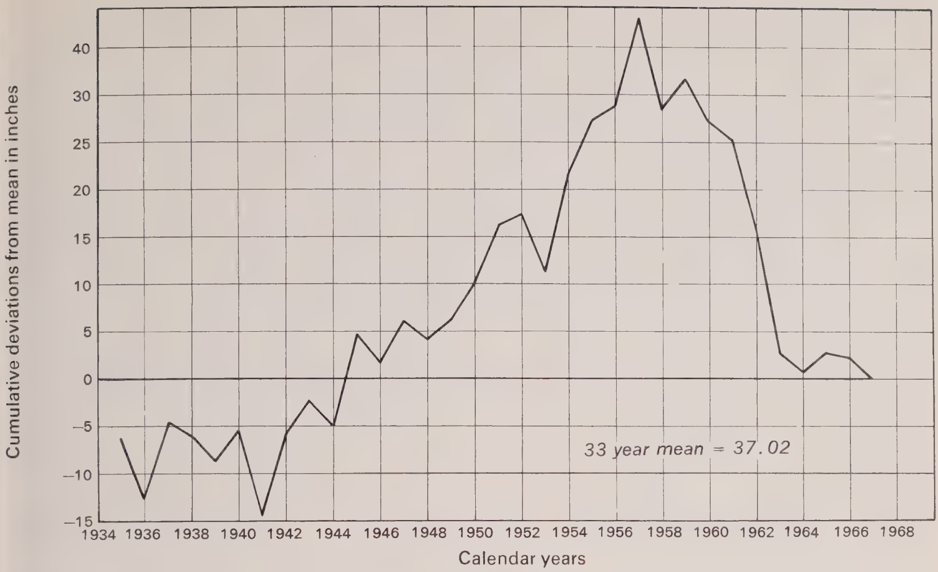


Figure 6. **Residual-mass curve of annual precipitation at Delhi, 1935-1967.**

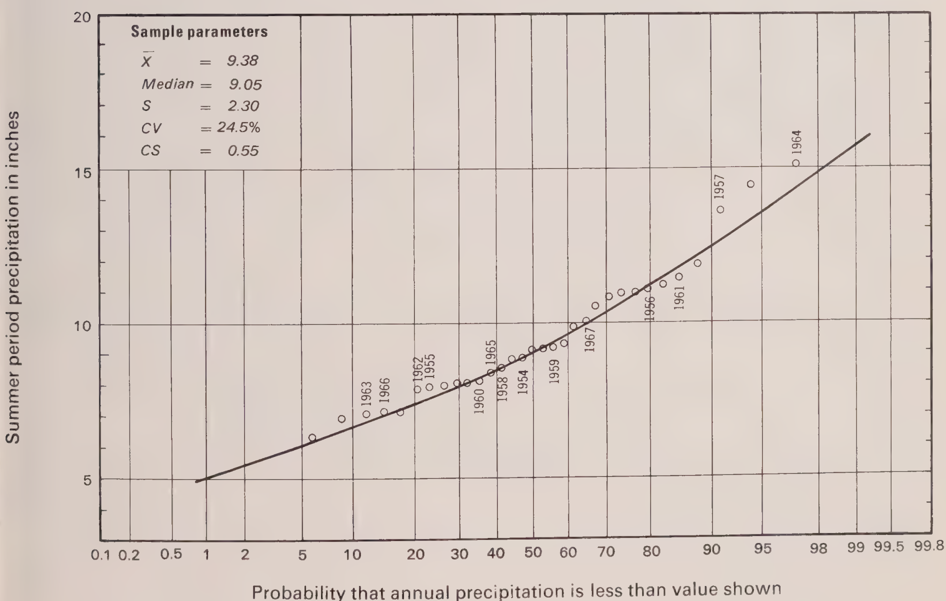


Figure 7. **Frequency curve of total June-August precipitation, Delhi, 1935-1967.**

Basin Precipitation

The basin precipitation values were derived using the Thiessen polygon method. In this method each precipitation station represents a proportion of the area of the basin dependent on its proximity to other stations. Figure 8 shows the selected precipitation stations from which the Thiessen polygon network was developed for year-round precipitation information (Network 1). Precipitation records are available for the St. Williams station since May, 1954, and for the others since the early 1930's. Precipitation estimates were determined for the basin above the Delhi streamflow station for the 30-year normal 1931-1960 and for the period October 1962 to September 1967; also for the basins above the Kelvin and Walsingham streamflow stations for the period January 1964 to December 1965.

The estimated monthly and annual precipitation values for the Big Creek basin above Delhi are shown in Table 6 for the long-term normal and for the 1963 to 1965 period. This table lists also similar data for the Big Creek basin above Kelvin and Walsingham for the period 1964 and 1965.

Table 6. Monthly and Annual Precipitation, Big Creek Basin, for Selected Years

(all values in inches)

Period	Big Creek Basin above Streamflow Gauging Stations Near							
	Kelvin		Delhi				Walsingham	
	1964	1965	Normal	1963	1964	1965	1964	1965
Jan	2.44	4.28	2.92	1.04	2.12	3.86	2.04	3.86
Feb	1.32	3.17	2.87	1.07	1.21	3.10	1.16	3.11
Mar	3.37	3.70	2.96	2.85	3.39	4.39	3.41	4.66
Apr	4.06	2.73	3.31	2.94	4.29	2.91	4.44	2.89
May	2.01	1.22	3.02	2.72	2.37	1.27	2.54	1.30
Jun	1.71	1.52	2.74	1.18	1.61	1.54	1.64	1.54
Jul	3.86	3.35	2.90	3.72	3.62	3.29	3.49	3.04
Aug	9.55	2.92	3.09	2.08	9.67	3.32	9.99	3.48
Sep	0.88	4.10	2.93	1.28	0.83	3.98	0.82	3.92
Oct	1.44	3.72	2.74	0.53	1.38	4.21	1.33	4.28
Nov	1.26	3.15	2.82	2.02	1.20	3.08	1.20	3.04
Dec	3.28	3.53	2.84	1.58	3.19	3.43	3.33	3.45
Yr.	35.18	37.39	35.14	23.01	34.88	38.38	35.39	38.57

The relatively uniform distribution of precipitation throughout the year as shown for the long-term normal does not hold throughout each individual year, as shown in Table 6.

A second precipitation station network, denser than the one shown in Figure 8, was available for the period May 1964 to November 1964, and was utilized to derive another set of sub-basin precipitation estimates for that period. Figure 9 shows the second precipitation station network and the associated Thiessen polygons (Network 2). Table 7 lists the two sets of basin precipitation estimates and their differences expressed in per cent of Network 2 estimates for the drainage areas terminating at the Kelvin, Delhi and Walsingham streamflow stations on Big Creek for the period May 1964 to November 1964 Comparison of sub-basin precipitation for the selected areas in the Big Creek basin for this period by means of two different networks shows that the sum of the monthly values are of the same general magnitude; however, it was found

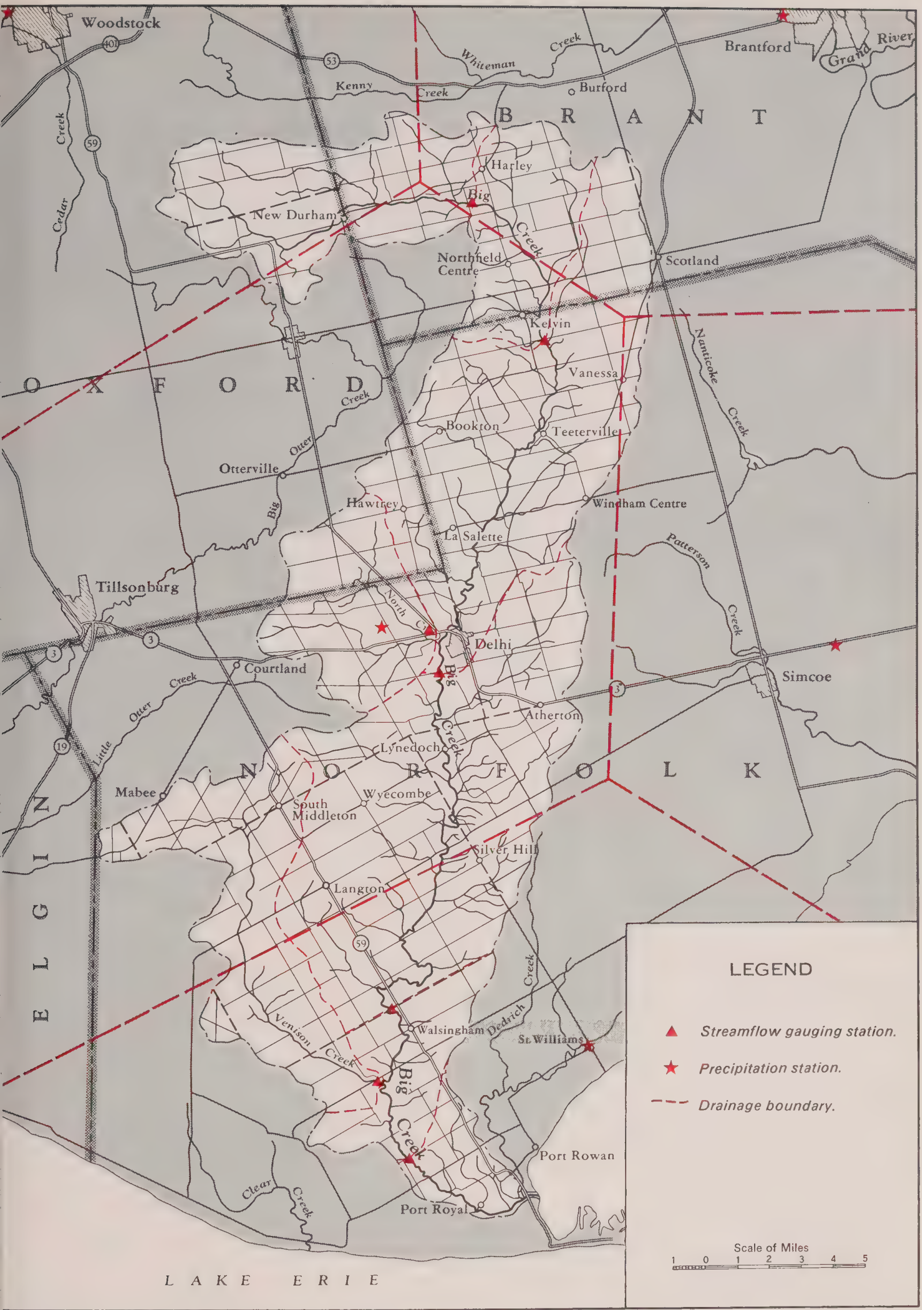


Figure 8. Location of long-term precipitation stations and associated Thiessen polygons used in calculating basin and sub-basin precipitation, Network 1, Big Creek basin.

that the individual monthly values varied considerably, in the extreme case by as much as 29 per cent, but generally agreed within 10 per cent when compared to one another.

It can be assumed from this comparison that the less dense network of long-term precipitation stations in and near the Big Creek basin can be used for annual estimates of basin precipitation but that on a monthly basis their estimates could differ considerably when compared to a denser network.

Estimated daily precipitation values are plotted as precipitation histograms on figures 21 and 22 and were considered in the selection of days during which total flow was estimated to be base-flow or ground-water runoff.

Surface Water

Surface waters are generally defined as all waters that occur on the land surface. In the Big Creek basin this includes water in streams, stream ponds, swamps and drainage ditches. The importance of surface water cannot be overstressed. Historically, it has always been an important source of water supply in an area because of its availability and accessibility. If maximum use is to be made of the resources, however, it is essential to know the quantity and distribution with respect to time and location. The establishment of this relationship is the primary purpose of this section.

The study of the quality and distribution of surface water in the Big Creek basin was accomplished through the interpretation and analysis of streamflow records, with the form of analysis selected being consistent with the availability, accuracy, and representativeness of the data. The intended use of the water resource also determines the method of analysis that may be employed, but because this survey was not project-oriented, a variety of methods was used.

In the succeeding passages information is presented on the consistency and accuracy of the available streamflow data, the methodology of analysis, and the surface-water runoff characteristics of the basin, based primarily on the analysis of streamflow data at five gauging stations; three on Big Creek and one each on North Creek and Venison Creek.

The consistency and accuracy of the available streamflow data were evaluated by means of the correlation and double-mass curve techniques. Two basic approaches are used to analyze and present the availability of surface water at most of the sites referred to in this report. In the first, emphasis is placed on the chronological sequence of streamflow events by plotting hydrographs. In the second, emphasis is placed on the frequency of occurrence, irrespective of chronological sequence. Frequency curves of high and low flows and flow-duration curves of mean daily and monthly flows fall into the second category.

Availability and Accuracy of Streamflow Data

Data on streamflow in the basin are available in the form of spot measurements and continuous records. Spot measurements are available for numerous locations throughout the basin. Twelve such gauging sites are shown on Map 2706-7 and the discharge measurements are listed in Table 8. Streamflow gauging stations for which continuous data are available are summarized in Table 9. The locations of stations in operation in the basin in 1964 are shown

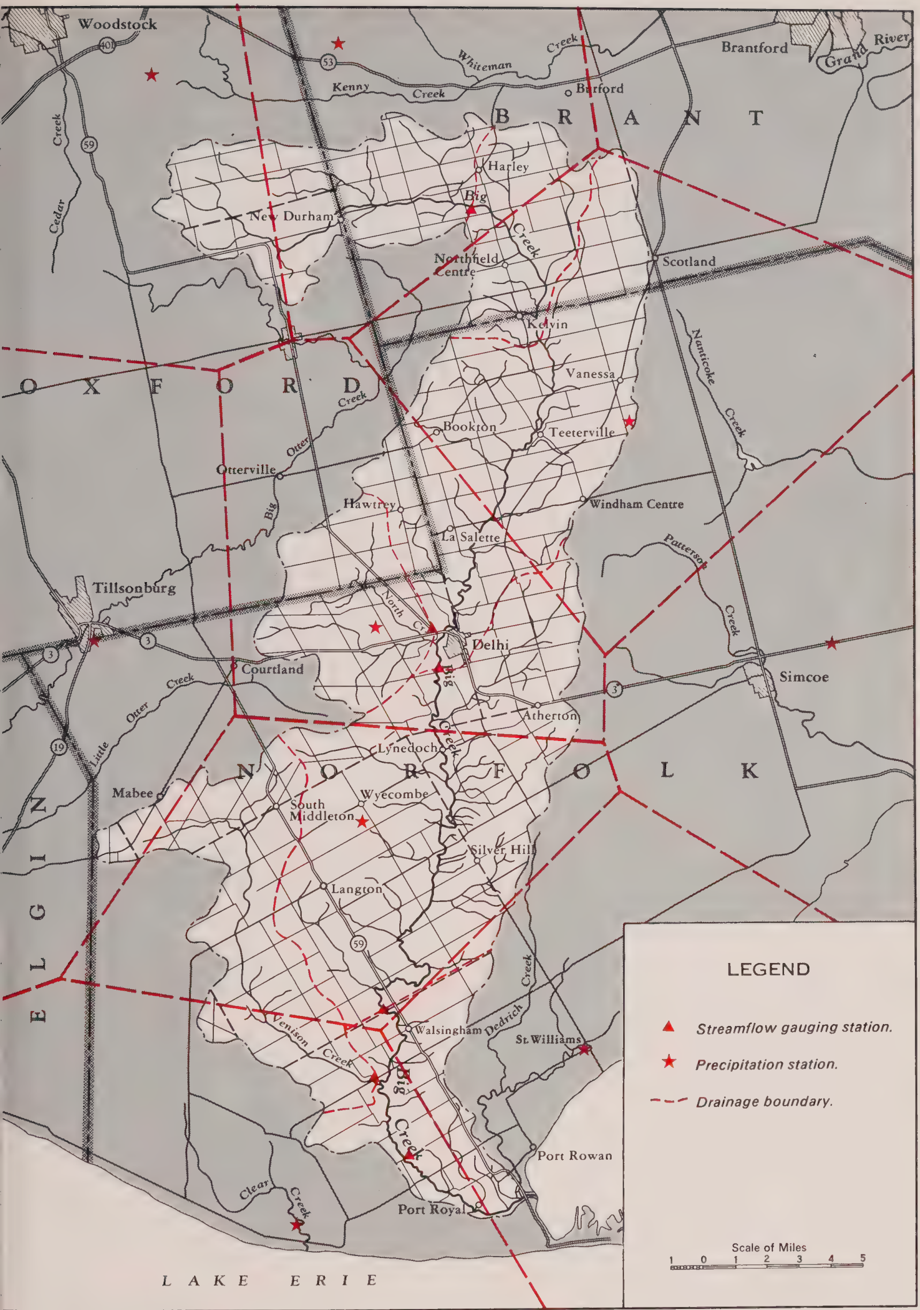


Figure 9. Location of long-term and short-term precipitation stations and associated Thiessen polygons used in calculating basin and sub-basin precipitation, Network 2, Big Creek basin.

Table 7. Comparison of Sub-Basin Precipitation Estimates, Big Creek Basin, May 1964 to November 1964

(all values in inches except per cent)

Period	Big Creek Basin above Streamflow Gauging Stations near								
	Kelvin			Delhi			Walsingham		
	Network 1	Network 2	Variation in per cent	Network 1	Network 2	Variation in per cent	Network 1	Network 2	Variation in per cent
May	2.01	2.10	- 4.3	2.37	2.20	7.7	2.54	2.44	4.1
Jun	1.71	2.07	-17.4	1.61	1.73	- 6.9	1.64	1.53	7.2
Jul	3.86	3.56	8.4	3.62	3.53	2.6	3.49	3.37	3.6
Aug	9.55	9.32	2.5	9.67	9.85	- 1.8	9.99	10.03	- 0.4
Sep	0.88	0.85	3.5	0.83	0.75	10.7	0.82	0.83	- 1.2
Oct	1.44	1.47	- 2.0	1.38	1.57	-12.1	1.33	1.64	-18.9
Nov	1.26	1.08	16.7	1.20	0.95	26.3	1.20	0.93	29.0
Total	20.71	20.45	1.3	20.68	20.58	0.5	21.01	20.77	1.2

Note: Network 1 is based on precipitation records from long-term meteorological stations only.

Network 2 is based on precipitation records from all suitable precipitation stations including those temporarily operated by members of the Norfolk Soil and Crop Improvement Association.

Table 8. Spot-Discharge Measurements, Big Creek Basin, 1964

(locations of sites are shown on Map 2706-7)

Date 1964		Gauging Sites and Discharges in cubic feet per second											
		1	2	3	4	5	6	7	8	9	10	11	12
		Venison Creek	Deer Creek	Silver-thorn Cr.	Cattle Creek	Big Cr. nr. Silver Hill	Trout Creek	Cranberry Creek	Stoney Creek	Deerlick Creek	Big Cr. above Delhi	Brandy Creek	Outlet Creek
May	6	33.3	-	-	-	-	-	-	-	-	-	-	-
	15	43.6	-	-	-	-	-	-	-	-	-	-	-
	24	21.7	-	-	-	-	-	-	-	-	-	-	-
	27	-	-	-	-	-	-	-	-	-	-	-	2.0
	28	-	-	5.6	-	-	-	4.5	5.9	3.4	36.2	-	-
	29	26.7	-	-	1.9	-	-	-	-	-	-	1.7	-
Jun	24	-	-	-	-	57.3	-	-	-	-	-	-	-
	29	-	-	-	-	-	-	-	-	2.3	24.6	2.1	3.2
	30	-	-	-	-	-	-	2.8	2.4	-	32.3	-	-
Jul	7	-	-	-	-	-	-	-	3.1	-	-	-	1.6
	8	-	-	3.9	-	-	5.5	-	-	-	-	-	-
	9	-	4.6	-	-	-	-	-	-	-	-	-	-
	14	-	-	-	-	-	-	-	7.5	-	-	-	1.9
	21	-	-	-	-	-	-	-	-	2.6	25.5	0.8	1.6
	22	-	-	5.0	1.8	50.2	5.5	3.1	3.0	-	-	-	-
	23	-	4.8	-	-	-	-	-	-	-	-	-	-
Aug	4	-	-	-	-	-	-	-	-	8.0	55.9	2.4	1.8
	5	-	6.2	5.3	2.9	121.0	5.8	5.1	10.0	-	-	-	-
	18	-	-	-	-	-	-	-	3.6	4.3	-	0.9	1.6
	19	-	4.8	4.1	1.9	73.4	5.1	3.5	-	-	-	-	-
Sep	1	-	7.3	5.4	-	150.0	-	-	-	-	-	-	-
	2	-	-	-	2.5	-	-	-	8.7	7.6	75.1	1.5	-

on Map 2706-7. Three of these are recording stations: on Big Creek near Kelvin and near Delhi, and on Venison Creek near Walsingham. Two of these are manual stations: on Big Creek near Walsingham and on North Creek at Delhi. The stations are operated by the Water Survey of Canada, Department of Energy, Mines and Resources. Data are also available for stations formerly operated by this agency or its predecessors. The Ontario Water Resources Commission operated recording stations on Big Creek near Harley and Port Royal from July 1964 to July and March 1965, respectively, and carried out numerous spot measurements.

The five main gauging stations were installed in the basin in or after 1953. The period of continuous record on streamflow in the basin is, therefore, relatively short. The reliability of the records appears to be satisfactory. The records are reported in average daily flows and this unit was used as the basis in most analyses.

Several small dams were operated upstream of most of the gauging stations and consideration was given to their regulatory effect. Of more importance was the effect on the streamflow created by the withdrawal of water for irrigative and municipal use. In the analyses adjustments were made for these withdrawals in order to present streamflow characteristics under natural conditions.

Table 9. Summary of Streamflow Gauging Stations, Big Creek Basin, as of September 1969

(locations of operational stations in 1964 are shown on Map 2706-7)

Station Name	Station Number[1]	Drainage Area[2] (sq. mi.)	Gauge Location	Period of Continuous Record	Type of Gauge
Big Creek near Harley	2GC-19	33.0	43° 02′ 59″N 80° 29′ 15″W	Jul '64 - Jul '65	R
Big Creek near Kelvin	2GC-11	53.4	42° 59′ 12″N 80° 26′ 42″W	Oct '63 - Sep '69	R
Big Creek near Delhi (Dick's Hill)	2GC-6	142	42° 50′ 15″N 80° 30′ 36″W	Sep '55 - Jul '63 Jul '63 - Sep '69	M R
Big Creek near Walsingham	2GC-7	221	42° 41′ 05″N 80° 32′ 15″W	Oct '55 - Sep '69	M
Big Creek near Port Rowan	2GC-1	270	42° 36′ - N 80° 30′ - W	Oct '45 - Jun '48	M
Big Creek near Port Royal	2GC-20	271	42° 37′ 05″N 80° 31′ 43″W	Jul '64 - Mar '65	R
North Creek at Delhi	2GC-5	22.3	42° 51′ 10″N 80° 30′ 35″W	Oct '54 - Jul '66	M
Venison Creek near Walsingham	2GC-9	34.7	42° 39′ 15″N 80° 32′ 55″W	Oct '63 - Sep '66	R
Venison Creek near Walsingham	2GC-21[3]	28.4	42° 40′ 27″N 80° 36′ 00″W	Oct '66 - Sep '69	R

1 Station numbers are those of the Canada Department of Energy, Mines and Resources unless otherwise indicated.

2 Based on OWRC calculations.

3 Gauge 2GC-21 replaced 2GC-9 and is located about 3 miles upstream from former site.

Correlation of Streamflow Records

A streamflow record is a sample of the flow in a stream and contains inherent measurement errors. Correlation with other records of similar conditions is a useful tool in checking for accuracy. Correlation of the records for the gauges at Big Creek near Kelvin and near Walsingham, North Creek at Delhi and Venison Creek near Walsingham was done using the Big Creek gauging station near Delhi as the index station because of its longer and apparently more reliable records. Both graphical and numerical methods of correlation were used.

Graphical correlation consisted of the method described in USGS Water Supply Paper 1541-C. Because of the basin conditions, only mean monthly values were used in the analyses.

The index of correlation, or its equivalent, the coefficient of correlation, and the standard error obtained from the graphical correlation between each of these stations and the index stations are tabulated below:

Station Location	Index of Correlation p	Coefficient of Correlation r	Standard Error	
			in log units	in percentage of regressed flow
Big Creek near Kelvin	0.98		0.128	-25.5 to +34.0
Big Creek near Walsingham		0.97	0.055	-12.0 to +13.5
North Creek at Delhi	0.93		0.082	-17.3 to +21.0
Venison Creek near Walsingham		0.95	0.059	-12.8 to +14.6

Values for the coefficient of correlation as presented above were also determined using a standard numerical method and were found to be very similar to the graphical method.

The correlation values are all near 1.00, indicating a very good relationship when all the mean monthly flows are considered to belong to one sample. No correlation was attempted for the individual calendar months primarily due to lack of sufficient data, but it is likely that their correlation values would be poorer for most months.

Test for Consistency of Records

The double-mass curve technique was used to test the consistency of the streamflow data as recorded at the streamflow gauging stations on North Creek at Delhi, Big Creek near Delhi, and near Walsingham. Each of the stations' cumulative flows were plotted against the cumulative averages of the runoff recorded at the three stations for the period October 1955 to May 1966. The runoffs for the individual stations, when plotted against the averages, have consistent relationships.

The double-mass curves show that the monthly runoff values for the stations investigated yield consistent records and that no major changes have taken place in the overall runoff patterns on a monthly basis during the period October 1955 to June 1966.

Methodology of Streamflow Analysis

The methods available for analyzing streamflow are varied, with the intended use usually determining the method employed. As this study was not

project-oriented, analyses were made in several different forms in order to provide as varied a description of the water resources as possible. The methods used for this report are described below and the results are given later in the section.

General Streamflow Characteristics

The chronological sequence of events and the variability of streamflow occurring at any site in the basin are most readily visible through the examination of hydrographs. Hydrographs were plotted for the five gauging stations in the basin for the water year ending in 1964. Details of the variability of flows are contained in the sections dealing with specific streams.

High-Flow Analysis

Analyses on high flows were based on the maximum mean daily discharge for each water year for those gauging stations having records for more than ten years. These discharges were selected and then tabulated in order of severity and their return periods determined using the formula:

$$Tr = \frac{n+1}{m}$$

where Tr = the average recurrence interval in years,

n = the number of values in the sample, and

m = the rank number of the individual value with the highest flow ranked 1.

The flows and recurrence intervals were plotted on logarithmic extreme probability paper and a theoretical curve fitted to the data using the "log Pearson Type III method" (Benson, 1968). This method is based upon the "log Pearson Type III" distribution, and is recommended by a United States federal interagency group for use by all federal agencies in flood frequency studies (Benson, 1968). It is considered to be better suited than the Type I extreme value or Gumbel distribution.

In this study, more satisfactory curves were obtained using the "log Pearson Type III" distribution than with the Gumbel distribution; however, because of the short period of record, these curves should not be used to make reliable predictions but rather to indicate the likely trend of the flood frequency distribution until such time as more data become available and more reliable curves can be fitted to them.

Low-Flow Analysis

Analyses of frequency of annual or seasonal low flows, or drought flows, are presented based on the lowest mean daily, or lowest average seven-, fifteen- and thirty-day flows for those gauging sites having adequate records.

Three time elements are involved in the description of low flow:

(1) the base unit of time from which a low flow is selected from the record,

(2) the length of time over which the flow is averaged, and

(3) the season in which the selection is made.

The year was selected as the base unit of time; however, this base unit does not necessarily provide a series of extreme values which in succeeding years are completely independent of each other. The time-lag factor in the hydrologic cycle influencing drought flows may extend over two or more years

in some drainage basins. Therefore, to obtain a true series of minima completely independent of each other, one should select perhaps a base period greater than one year. In this study, however, the one-year base unit was adopted because of the short period of streamflow records in the basin.

The second time element, the time over which the flow is averaged, may be taken as a day or a period of any relatively small number of consecutive days. Four separate time periods were selected for this study: the minimum daily, and the minimum consecutive 7-day, 15-day, and 30-day averages.

The third time element, the seasonal factor, distinguishes between summer-fall, and winter discharges. Low flows associated with severe freezing conditions and ice-covered streams belong definitely to a different set of values than those associated with the open-water low-flow period.

In this basin, the summer-fall season low flows are generally smaller than those of the winter season, and are of greater importance to the inhabitants of the basin because of the larger and varied demands placed upon the streams during the growing season. Therefore, while retaining the year as the base time unit, the analysis of minimum flows was concentrated on a "summer-fall" season, June 1 to November 30.

After the compilation of the low-flow data, it was found that most of the extreme low flows occurred during the period June 16 to August 20, which is designated as the prime-irrigation period in this report. To obtain estimates of the natural minimum low flows in the basin, a second set of minimum low flows was prepared based on the period August 21 to November 30. This period will be referred to as the "post-irrigation period" in subsequent references. The starting date, August 21, is based on the irrigation practices at the Delhi Research Station where no tobacco lands are irrigated after August 20.

In general, the post-irrigation period minimum low flows can be expected to be lower than the minimum low flow that would have occurred during the prime-irrigation period if no water had been withdrawn for irrigation; however, how much larger the flows, during the irrigation period, would have been than those observed during the post-irrigation period is difficult to assess. Several factors which affect the post-irrigation low flows, as compared to those of the irrigation period, are presented below:

1. The ground-water discharge to the streams is generally smaller during the post-irrigation period than that during the prime-irrigation period. Under normal climatic conditions prevailing in the basin, the ground-water discharge recedes from the spring high to the fall low prior to the heavy fall rains. The summer-early fall precipitation is normally not sufficient to satisfy the evapotranspirative demands of the basin, resulting in generally lowered soil-moisture storage and no or very limited recharge to the ground-water storage in the surficial aquifers. Due to lack of recharge, the water-table is lowered during this period, resulting in lower hydraulic gradients which, in turn, result in lower ground-water discharge.
2. Due to the extensive and intensive water withdrawal for irrigation from dug-out ponds connected to the ground-water table and well points, the surficial aquifers are often mined during the irrigation period. The effects of this artificial lowering of water-table conditions at many locations in the basin may be felt in a reduction of streamflow which may extend well into the post-irrigation period.
3. Evapotranspirative demands are smaller during the post-irrigation period and may tend to increase streamflow. Most crops will have been harvested prior to August 21, with the exception of tobacco and corn, but even their transpirative demands will be smaller as the crops have

matured and are being harvested. Other permanent vegetative cover will remain the same, but maturing of this cover and the shedding of leaves by deciduous trees will further reduce evapotranspiration. Also, vegetation having roots within the ground-water table, or in the capillary fringe above it, *phreatophytes*, will not require as much water as during the summer period, and will result in lower base-flow recession rates.

Low-flow frequency curves for the previously defined low-flow periods were prepared as follows. The data for each sample were tabulated in order of increasing severity and their return periods determined using the formula

$$Tr = \frac{n+1}{m}$$

where	Tr	=	the average recurrence interval in years,
	n	=	the number of values in the sample, and
	m	=	the rank number of the individual value, with the lowest flow ranked 1.

The low-flow values were then plotted against their recurrence interval on logarithmic extreme probability paper.

To facilitate comparisons in minimum low flows between streams and reaches of streams in the Big Creek basin, two low-flow indices are presented: the yield and the variability ratio. The yield is defined as discharge per square mile of tributary drainage area and is based on the flow as measured at a streamflow gauging station. It provides a direct comparison between streamflows measured at stations having different tributary drainage areas.

Some streams or reaches of streams show wide variation from year to year in the severity of their low flows, while others are more stable. The standard deviation, the conventional measure of degree of variability, cannot be used due to the asymmetrical nature of the low-flow distributions. The concept of a simple ratio is used instead; it will answer directly what proportion of the normal low flow is the rare low flow. The variability ratio used is the one employed by Velz (1960), in which the normal low flow is taken as the most probable value and is read from the frequency curve of low flow developed from the sample data and the rare low flow is taken arbitrarily as the once-in-ten-year value on this curve. A variability ratio of near unity would indicate a stable stream while a small ratio would indicate a stream with a high degree of variation in low flow from year to year with a risk of occasional extremely severe low flows.

Flow-Duration Analysis

The flow-duration analysis consists of the manipulation of streamflow records of a gauging station so that duration curves can be prepared of the flow at that station. A flow-duration curve is a cumulative frequency curve that shows the percentage of time specified streamflows are equalled or exceeded during a given period. It combines in one curve the flow characteristics of a stream throughout its range of discharge and period of record without regard to the sequence of streamflow events. It is a useful characteristic of a drainage basin or sub-basin and is used in comparisons between the flow characteristics of streams or reaches of streams. It has application, especially when based upon a long period of record, in predicting the distribution of future flows and, as such, is useful in the study of water-supply problems, power developments, and dilution and disposal of sewage and industrial waste materials. The effects of ground-water discharge on streamflow are usually reflected in the lower

section of the duration curve. Under normal runoff conditions, without streamflow interference due to temporary storage or permanent water withdrawal, the slope of this section indicates whether the stream has stable base-flow conditions.

The flow-duration curves prepared for streams in the basin were based on the method described by Searcy (1959). The method consists basically of arranging the streamflow data, whether daily, weekly or monthly, according to magnitude, and computing the percentage of time over the total period during which flow equalled or exceeded specified values.

When comparing flow-duration curves for meteorologically similar areas, it is necessary that these curves be based on the same period of record. It is not sufficient that the periods be of equal length; they should be for the same period of years so that there is a maximum probability that the specific meteorological events that are reflected in one record will also be be reflected in the other.

Flow-duration curves of short periods adjusted to represent long-term conditions were prepared using the index station method as described by Searcy (1959). The streamflow gauging station on Big Creek near Delhi was selected as the index station. This method consists basically of establishing a curve of relation between a long-term and short-term station, and using it to obtain an estimate of the flow-duration curve for any period for which a flow-duration curve is available at the long-term or index station. This curve of relation is based on flow-duration curves for both the short-term and the index station covering the same time period.

Separation of Streamflow into Components

An effort was made to separate total streamflow into its two main components, surface or direct runoff and baseflow or ground-water discharge. A hydrograph of base flow was prepared through the use of a relationship between average ground-water stage in a number of observation wells and the same-day average ground-water discharge at the streamflow gauging station. The establishment of this relationship is discussed elsewhere in this report. Surface or direct runoff was considered to be the difference between the two hydrographs.

Big Creek

Big Creek rises about nine miles to the west of the hamlet of Harley and flows in a general easterly direction to a point two miles southeast of Harley from where it flows in a general southerly direction to Lake Erie, passing through Teeterville, Delhi, Walsingham and Port Royal. The creek outlets into Long Point Bay on Lake Erie, about one and one-quarter miles south of Port Rowan.

Big Creek drains a total of 281 square miles and has a main channel 55.6 miles in length. It has 13 tributaries varying in length from 2.5 to 14.2 miles. Its extreme gradients vary from 35.71 feet per mile in its headwaters to 0.38 feet per mile in its lowest reach. It has a total fall of 428 feet and an average gradient of 7.71 feet per mile. Its tributaries have gradients varying from a high of 37.5 to a low of 16.0 feet per mile. Big Creek and its tributaries run in deep river valleys which break the general scene of fairly flat to undulating topography. Big Creek's valley below Delhi reaches a depth of 100 feet or more and varies from one-quarter to one-half mile in width (Big Creek Region Conservation Report, Ontario Department of Planning and Development, 1958). In the headwater areas of Big Creek and many of its tributaries, improvement of drainage has been necessary because of very low gradients (Map 2706-8).

Variability of Streamflow

Hydrographs of mean daily flows are presented in Figure 10 to show the variability of streamflow in Big Creek. The hydrographs are for gauging stations on Big Creek near Kelvin, Delhi and Walsingham for the water year October 1, 1963, to September 30, 1964, and represent flows in the upper, middle and lower parts of the basin, respectively. The figure shows the relative magnitude of streamflow occurring simultaneously at each site and the similarity in the pattern of streamflow.

High flows occur during the spring freshet when the winter's precipitation, stored in the form of snow and ice, melts and is carried off by the streams in the basin. Other high flows occur after severe summer and fall rainstorms. Figure 10 shows that in 1964 high flows occurred during the months of March, April, May and August.

The effects of large rain storms on the runoff are apparent during the month of August 1964. Figures 21 and 22 show the daily precipitation distribution and streamflow for August 1964 for Big Creek near Delhi and Walsingham. The effects of antecedent precipitation on the runoff from the August 21-22 storm, after soil-moisture deficiency had been satisfied during earlier rainfalls are also evident.

In 1964 relatively dry weather conditions prevailed during the growing season in the last week of June, the second half of July, and the first days of August. The reduction in streamflow due to large water withdrawals for irrigation during the month of July are clearly visible in Figure 10. Based on normal streamflow recession, the natural streamflow would have been much greater.

High Flows

High flows, commonly called flood flows, represent large quantities of water that generally run off in relatively short periods of time. Knowing their magnitude and frequency is therefore essential to good management. Floods in the Big Creek basin were noted as early as 1796. A comprehensive account of these early floods is given in the Big Creek Region Conservation Report, Water Section (Ontario Department of Planning and Development, 1958). Records on high flows in Big Creek are available for the streamflow gauging stations near Delhi and near Walsingham since 1955, near Kelvin since 1964 and near Port Rowan for the period 1945-1948.

The maximum mean daily flows for Big Creek, as recorded at the Delhi and Walsingham gauging stations, are tabulated in Table 10. Flood frequency curves based on the data in the table are shown in Figure 11. Due to the short period of record, these frequency curves may not be very reliable but they indicate the approximate magnitude of high flows or floods at specific recurrence intervals in years.

The maximum mean daily flows occurred most often in March and April, the spring freshet period. Other large flows have occurred after mid-winter thaws or during summer-fall storms, but were smaller in magnitude over the period record. In some other basins in southern Ontario, having longer periods of streamflow records, the summer-fall storm season yielded the highest recorded floods, such as occurred during Hurricane Hazel in October 1954. Similar conditions may occur in the Big Creek Basin.

Records of instantaneous peak flows of Big Creek are available since October 1963 at the automatic stage-recording stations near Kelvin and Delhi. The instantaneus peak flows, the same-day mean daily flows and their ratios at these gauging stations for the water years 1963-1964 to 1966-1967 are shown in Table 11. The ratios at each site show that the difference between the two flows can be very significant.

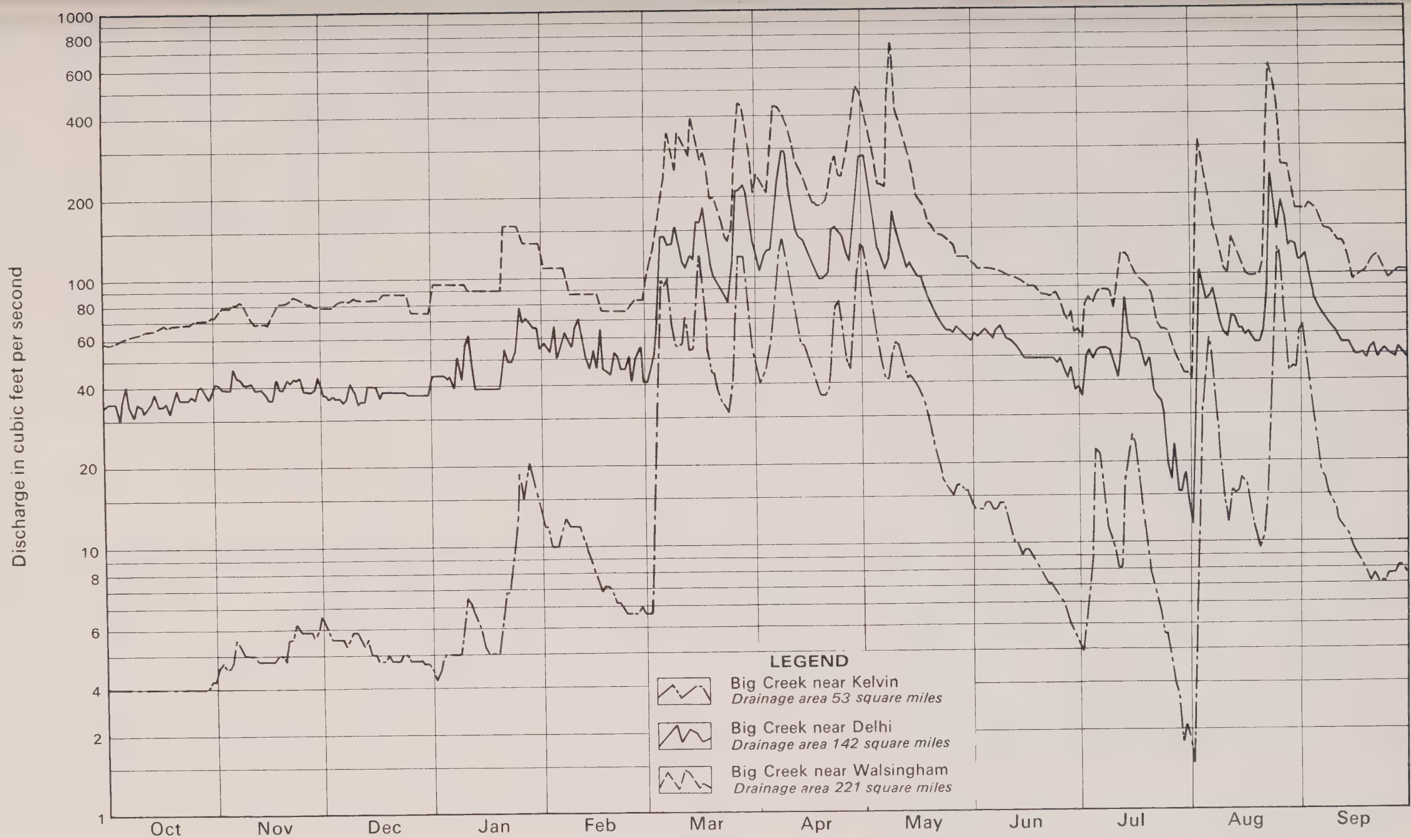


Figure 10. Streamflow hydrographs, Big Creek near Kelvin, near Delhi, and near Walsingham for water year ending 1964.

Table 10. Annual Maximum Mean Daily Discharges, Big Creek Basin

(discharges expressed in cubic feet per second)

Water Year	Big Creek near Delhi		Big Creek near Walsingham	
	Date	Discharge	Date	Discharge
1955-56	March 8	1,630	March 11	1,400
1956-57	April 7	1,060	April 8	985
1957-58	December 28	740	December 23	765
1958-59	March 21	783	April 4	828
1959-60	March 31	4,910	April 1	3,060
1960-61	April 26	364	April 28	695
1961-62	March 13	886	May 14	1,020
1962-63	March 28	635	March 20	953
1963-64	April 8	297	May 9	744
1964-65	March 6	3,750	March 6	6,100
1965-66	February 13	461	February 12	777
1966-67	December 11	758	December 11	1,010

Table 11. Maximum Instantaneous and Same-Day Mean Daily Discharges, Big Creek Basin, 1964-1967

(discharges expressed in cubic feet per second)

Stream and Gauging Station	Water Year	Maximum Instantaneous Discharge	Date of Occurrence	Same Day Mean Discharge	Discharge Ratio Instantaneous / Same Day Mean
Big Creek near Kelvin	1963-1964	146	Apr. 8	139	1.05
	1964-1965	1910	Feb. 11	1280	1.49
	1965-1966	405	Feb. 12	332	1.22
	1966-1967	926	Apr. 3	545	1.70
Big Creek near Delhi	1963-1964	397	Apr. 8	297	1.34
	1964-1965	5230	Mar. 7	3100	1.69
	1965-1966	493	Feb. 13	461	1.07
	1966-1967	938	Apr. 4	638	1.47
Venison Creek near Walsingham	1963-1964	112	Aug. 23	107	1.05
	1964-1965	-	Mar. 6	1580 (e)	-
	1965-1966	225	Feb. 12	207	1.09

(e) = estimated discharge

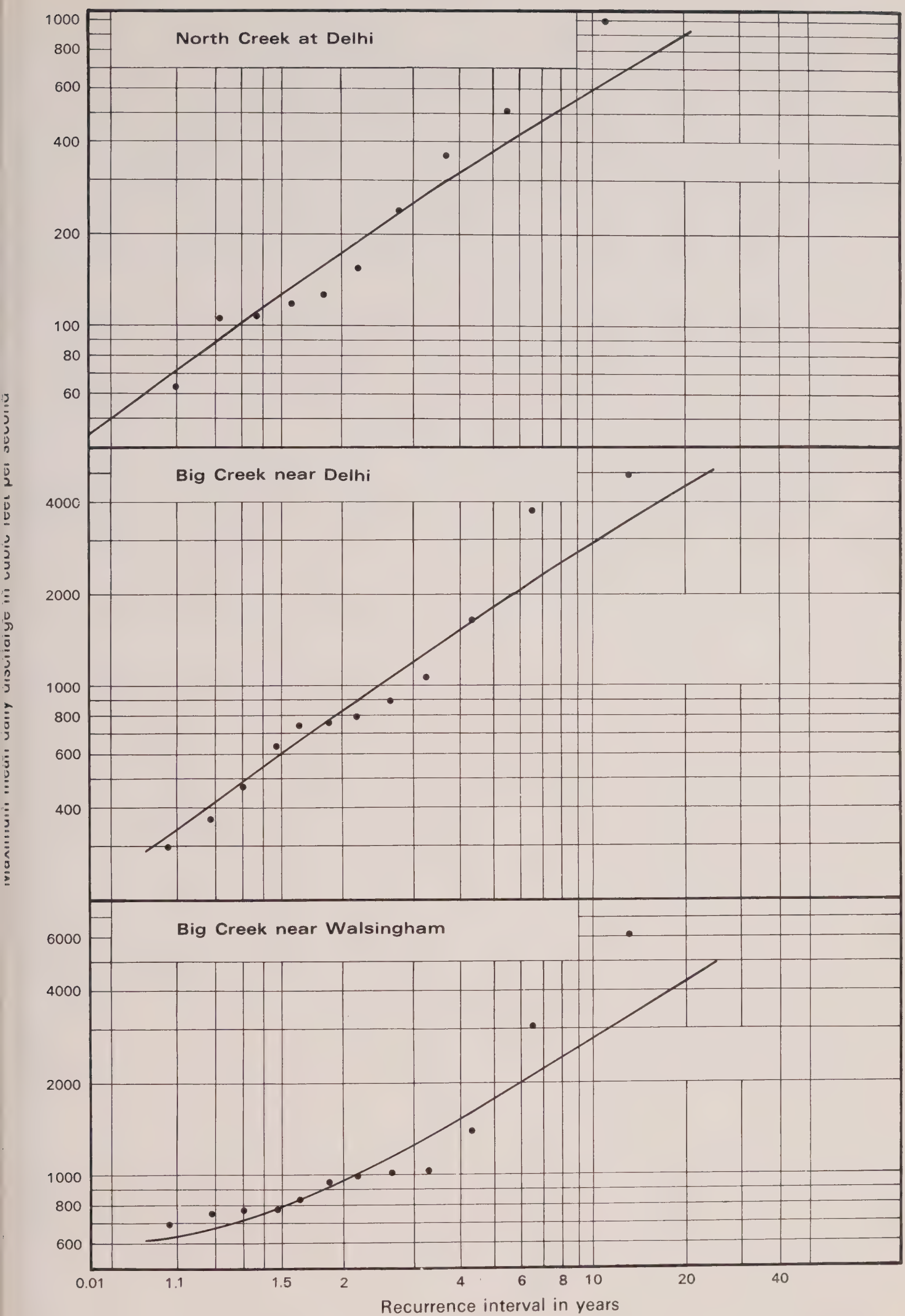


Figure 11. Frequency curves of annual high flows, North Creek at Delhi, 1954-1963, Big Creek near Delhi and near Walsingham, 1955-67.

Low Flows

Low flows are often called drought flows. Their magnitude and frequency of occurrence are factors to be considered in water use and management programs.

Low flows occur naturally during the summer-fall period but are influenced, during part of the period, by water withdrawn for irrigation. Dams in the Big Creek basin would tend to influence low flows further during this time, but because the dams are small and the control-works stationary, their effects on low flows in the larger streams may be negligible.

Because of the influencing effects, analyses of low flows were made for three specific time periods:

(1) the summer-fall season — June 1 to November 30,

(2) the prime-irrigation period — June 16 to August 20,

(3) the post-irrigation period — August 21 to November 30.

The minimum average discharges as recorded at three streamflow gauging stations on Big Creek for several specific periods are presented in tables 12 to 16. Table 12 lists the data for Kelvin, tables 13 and 14 for Delhi and tables 15 and 16 for Walsingham. Frequency curves based on the data were prepared for the Delhi and Walsingham gauging stations for both the summer-fall season and the post-irrigation period and are shown in figures 12 and 13. The figures present also the time range of occurrence for the minimum flows for periods of specific length and illustrate by means of a special symbol the individual values which occurred within the prime-irrigation period June 16 to August 20.

To assess the effects of irrigation on the natural low summer flows, a further study of the Big Creek discharges, as recorded at the Delhi gauging station, was conducted for the summer periods over the years of record. This study entailed the preparation of hydrographs based on the daily records as recorded at the gauge and the superimposition of sections of the base-flow recession curve during periods of no or little precipitation. The resulting composite curves, consisting of sections of recorded and estimated natural discharges, present subjective curves which likely approach the streamflow conditions if no or limited irrigation had been practised during the summer periods upstream of the Delhi gauge. From the theoretical curves of natural flow, the minimum seven-day average discharge was determined for each of the prime-irrigation periods, June 16 to August 20, over the years of record. Table 17 lists these values together with those based on recorded discharges. It presents also the recorded and similarly adjusted minimum seven-day average discharges for the summer-fall season for Big Creek near Delhi.

Table 12. Minimum Average Discharges and Dates of Occurrence, Big Creek near Kelvin, for Summer-Fall Season.

(discharges, Q, expressed in cubic feet per second, date is starting date of period)

Year	One-Day		Seven-Day		Fifteen-Day		Thirty-Day		Month	
	Q	Date*	Q	Date	Q	Date	Q	Date	Q	Date
1964	1.5	Aug	2.4	26/ 7	4.5	19/ 7	6.7	1/10	6.8	Oct
1965	0.2	Jul	1.3	27/ 7	1.8	17/ 8	2.2	29/ 7	2.3	Aug
1966	0.0	Jul	0.1	21/ 7	0.6	13/ 7	1.7	11/ 7	2.1	Jul
1967	2.4	Sep	2.4	14/ 9	2.7	7/ 9	3.6	30/ 8	3.7	Sep

* No exact date shown for minimum one-day discharges as some occurred on several dates during month.

able 13. **Minimum Average Discharges and Dates of Occurrence, Big Creek near Delhi, for Summer-Fall Season 1956-1967.**

(discharges, Q, expressed in cubic feet per second, date is starting date of period)

ear	One-Day		Seven-Day		Fifteen-Day		Thirty-Day		Month	
	Q	Date *	Q	Date	Q	Date	Q	Date	Q	Date
956	6	Aug	20	1/ 8	34	28/ 7	38	29/ 7	66	Jul
957	32	Aug	39	19/ 8	42	11/ 8	43	12/ 8	61	Jun
958	15	Aug	25	1/ 8	30	25/ 7	34	24/ 7	39	Aug
959	10	Aug	13	31/ 7	21	8/ 7	22	10/ 7	27	Jul
960	34.2	Jul	37.1	23/ 9	38.3	21/ 9	41.7	6/ 9	43.4	Sep
961	25.0	Jul	30.8	17/ 9	34.4	16/ 9	35.8	10/ 9	45.1	Sep
962	18.2	Jul	26.1	14/ 7	27.9	6/ 7	33.0	29/ 6	34.4	Jul
963	14.1	Jul	18.7	8/ 7	22.9	5/ 7	28.3	29/ 6	31.8	Jul
964	11.7	Aug	16.3	26/ 7	26.1	19/ 7	40.1	4/ 7	41.9	Jul
965	10.8	Jul	20.4	26/ 7	31.1	21/ 7	37.5	24/ 7	41.3	Aug
966	14.9	Jul	17.7	20/ 7	22.6	15/ 7	33.0	3/ 7	33.6	Jul
967	36.0	Aug	45.3	1/ 8	49.9	26/ 7	52.3	23/ 7	53.8	Sep

* No exact date shown for minimum one-day discharges as some occurred on several dates during month.

able 14. **Minimum Average Discharges and Dates of Occurrence, Big Creek near Delhi, for Prime-Irrigation and Post-Irrigation Periods.**

(discharges, Q, expressed in cubic feet per second, date is starting date of period)

Year	Prime-Irrigation Period June 16 to August 20				Post-Irrigation Period August 21 to November 30			
	One-Day		Seven-Day		One-Day		Seven-Day	
	Q	Date*	Q	Date	Q	Date*	Q	Date
1956	6	Aug	20	1/ 8	16	Aug	41	21/ 8
1957	37	Aug	43	14/ 8	32	Aug	41	21/ 8
1958	15	Aug	25	1/ 8	30	Aug	43	1/ 9
1959	10	Aug	13	31/ 7	43.8	Oct	45.9	22/10
1960	34.2	Jul	44.5	12/ 7	34.2	Sep	37.1	23/ 9
1961	25.0	Jul	42.4	20/ 7	27.0	Sep	30.8	17/ 9
1962	18.2	Jul	26.1	14/ 7	35.4	Aug	38.7	28/ 8
1963	14.1	Jul	18.7	8/ 7	27.9	Sep	33.6	8/10
1964	11.7	Aug	16.3	26/ 7	45.8	Oct	48.3	14/10
1965	10.8	Jul	20.4	26/ 7	37.0	Sep	38.9	17/ 9
1966	14.9	Jul	17.7	20/ 7	39.5	Oct	41.2	27/ 8
1967	36.0	Aug	45.3	1/ 8	43.0	Aug	47.4	14/ 9

* No exact date shown for minimum one-day discharges as some occurred on several dates during month.

Table 15. **Minimum Average Discharges and Dates of Occurrence, Big Creek near Walsingham, for Summer-Fall Season 1956-1967.**

(discharges, Q, expressed in cubic feet per second, date is starting date of period)

Year	One-Day		Seven-Day		Fifteen-Day		Thirty-Day		Month	
	Q	Date*	Q	Date	Q	Date	Q	Date	Q	Date
1956	91	Aug	125	28/ 7	132	24/ 7	135	24/ 7	146	Jul
1957	106	Aug	112	18/ 8	119	10/ 8	124	11/ 8	141	Aug
1958	60	Aug	68	14/ 8	74	10/ 8	74	25/ 7	77	Aug
1959	60	Aug	62	2/ 8	66	26/ 7	68	11/ 7	75	Jul
1960	93	Oct	95	11/10	100	6/10	104	23/ 9	105	Oct
1961	90	Oct	92	25/10	93	25/10	94	16/10	95 (e)	Oct
1962	54	Jul	56	15/ 7	56	7/ 7	63	1/ 7	63	Jul
1963	43.2	Jul	44.8	9/ 7	47.3	8/ 7	50.5	29/ 6	70.7	Oct
1964	40.4	Aug	43.5	26/ 7	58.5	18/ 7	76.7	3/ 7	77.8	Jul
1965	61.0	Jul	62.8	26/ 7	66.1	18/ 7	77.3	31/ 8	79.1	Sep
1966	33.8	Jul	35.1	21/ 7	45.0	14/ 7	60.0	14/ 7	66.2	Jul
1967	76.8	Aug	83.1	15/ 9	84.2	7/ 9	89.0	23/ 8	91.8	Sep

(e) = estimated discharge

* No exact date shown for minimum one-day discharges as some occurred in several dates during month.

Table 16. **Minimum Average Discharges and Dates of Occurrence, Big Creek near Walsingham, for Prime-Irrigation and Post-Irrigation Periods, 1956-1967.**

(discharges, Q, expressed in cubic feet per second, date is starting date of period)

Year	Prime-Irrigation Period June 16 to August 20				Post-Irrigation Period August 21 to November 30			
	One-Day		Seven-Day		One-Day		Seven-Day	
	Q	Date*	Q	Date	Q	Date*	Q	Date
1956	91	Aug	12	29/ 7	123	Aug	149	16/11
1957	116	Aug	121	14/ 8	106	Aug	123	2/ 9
1958	60	Aug	68	14/ 8	81	Sep	82	27/ 8
1959	60	Aug	62	2/ 8	77	Aug	82	17/ 9
1960	103	Jul	105	6/ 7	93	Oct	95	12/10
1961	96	Jul	96	21/ 7	90	Oct	92	26/10
1962	54	Jul	56	15/ 7	54	Sep	59	28/ 8
1963	43.2	Jul	44.8	9/ 7	67.6	Oct	68.2	1/10
1964	40.4	Aug	43.5	26/ 7	93.0	Nov	94.4	14/11
1965	61.0	Jul	62.8	26/ 7	71.4	Sep	71.9	21/ 9
1966	33.8	Jul	35.1	21/ 7	66.0	Sep	68.3	27/ 8
1967	76.8	Aug	84.9	31/ 7	78.0	Sep	83.1	15/ 9

* No exact date shown for minimum one-day discharges as some occurred on several dates during month.

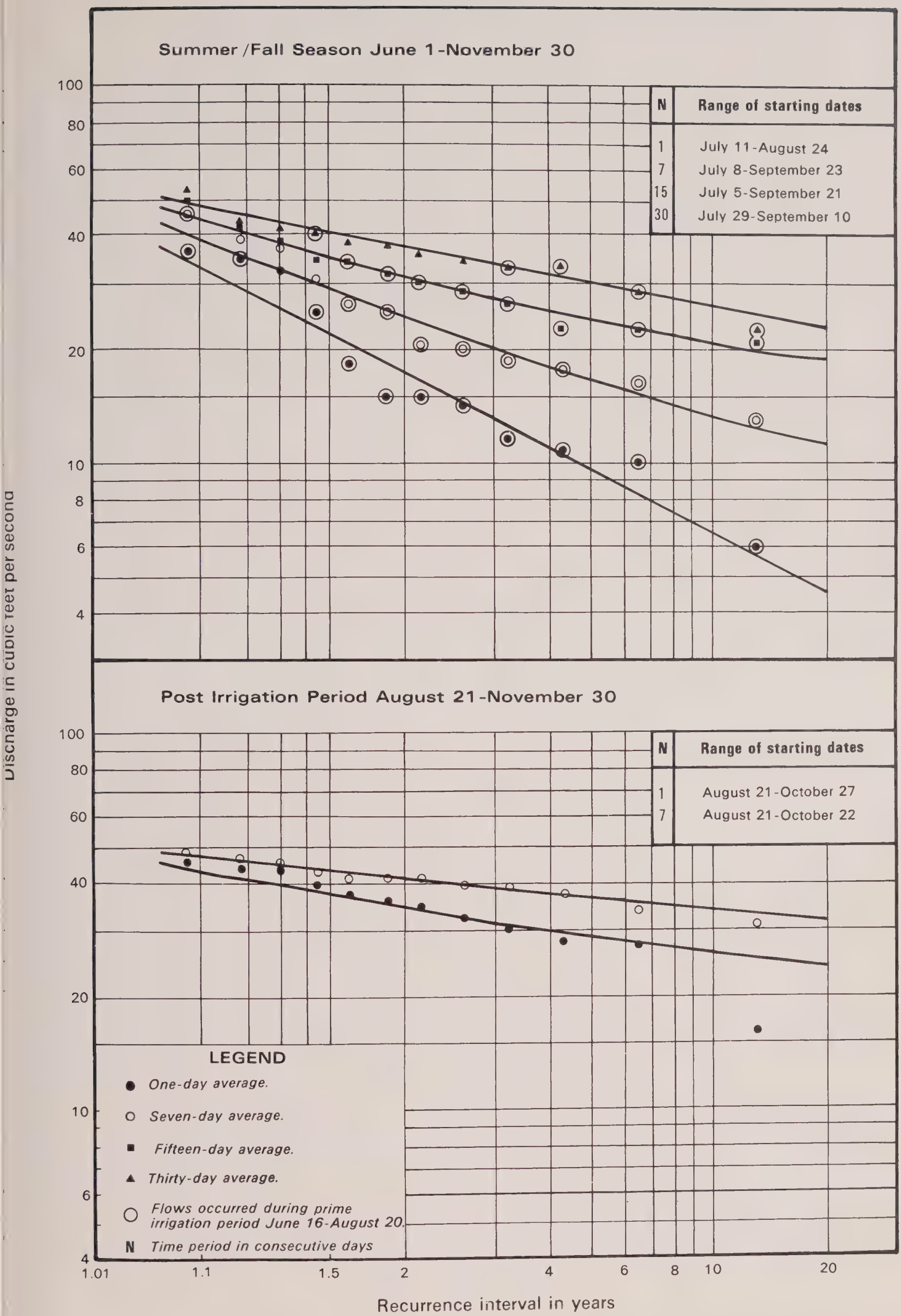


Figure 12. Frequency curves of low flows, Big Creek near Delhi, 1956-1967.

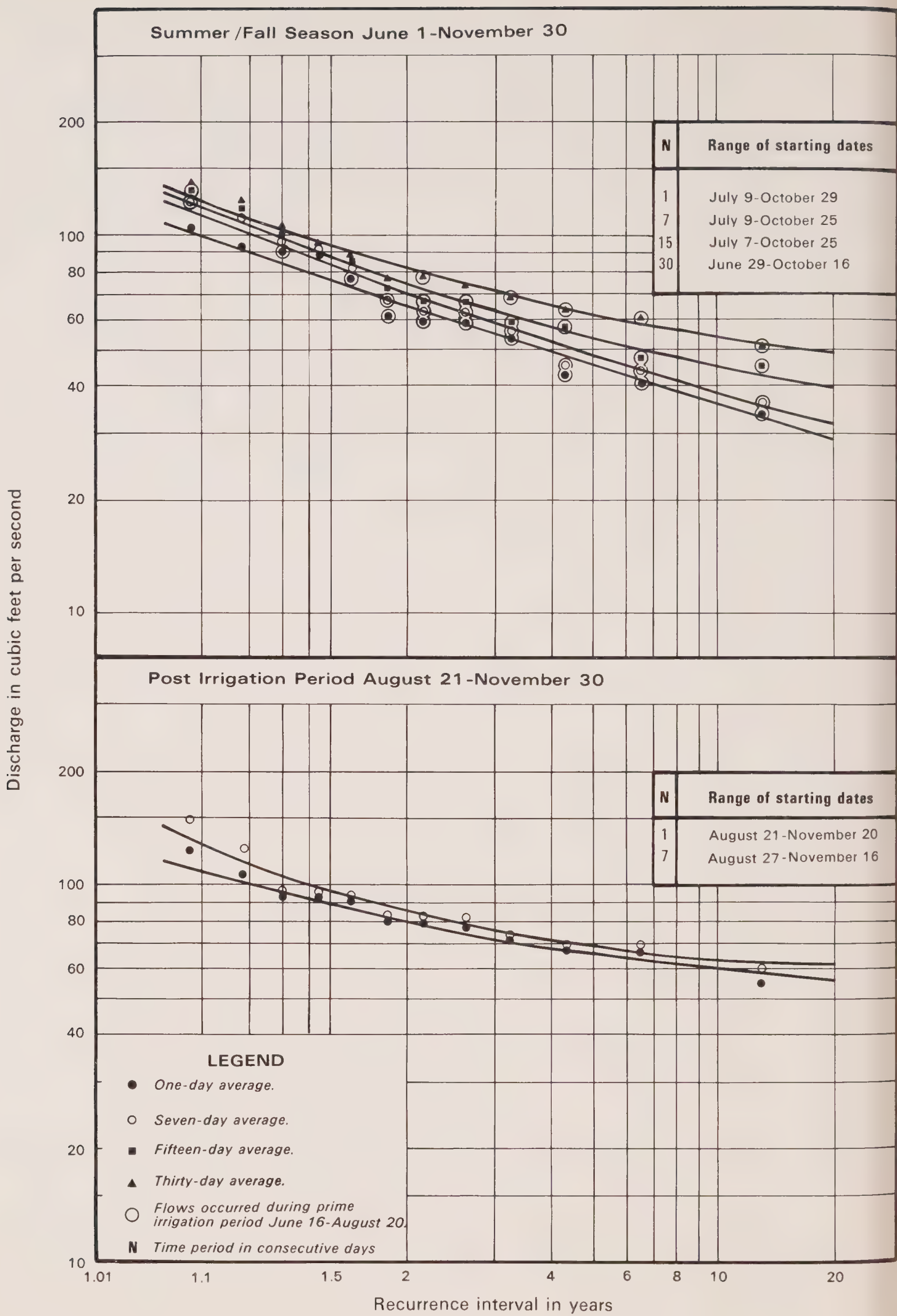


Figure 13. Frequency curves of low flows, Big Creek near Walsingham, 1956-1967.

Table 17. **Actual and Adjusted Minimum Seven-Day Average Discharges for Prime-Irrigation Period and Summer-Fall Season, 1956-1957, Big Creek near Delhi**

(discharges expressed in cubic feet per second)

Year	Prime-Irrigation Period June 16 — August 20		Summer-Fall Season June 1 — November 30	
	Actual	Adjusted for Water Withdrawal	Actual	Adjusted for Water Withdrawal
1956	20	52	20	41
1957	43	47	39	45
1958	25	42	25	42
1959	13	40	13	40
1960	44	57	37	37
1961	42.4	53	30.8	31
1962	26.1	44	26.1	39
1963	18.7	38	18.7	34
1964	16.3	42	16.3	42
1965	20.4	40	20.4	39
1966	17.7	43	17.7	41
1967	45.3	46	45.3	46

Figure 14 presents the frequency curves of minimum seven-day average discharges for the prime-irrigation and post-irrigation periods and the summer-fall season. It shows two frequency curves based on recorded and adjusted discharges for both the prime-irrigation period, curves A-2 and A-1, respectively, and the summer-fall season, curves C-2 and C-1, respectively. The frequency curve for the post-irrigation period, curve B, is based on recorded discharges. Curve B was transposed to the graphs for each of the other periods for comparison purposes.

The following observations are drawn from Figure 14:

1. The water withdrawals for irrigation purposes alter the low-flow distribution greatly in Big Creek.
2. The frequency curve based on the post-irrigation period is a good indicator of the potential low-flow yield for the summer-fall season, but it provides an underestimate of the potential low-flow yield during the prime-irrigation period.

In order to draw comparisons between the low flows in different parts of the basin, two low-flow indices were calculated, the yield per square mile for the basins above the Delhi and Walsingham stations and the severity index for the flows at these stations. The low-flow yield characteristics are shown in tables 18 and 19 for three recurrence intervals and the low-flow severity indices are shown in Table 20. The recurrence intervals are the most-probable, selected as the 1.58-year intervals, and the five-year and ten-year intervals. The tables are based on low flows obtained for the three specific time periods previously defined, namely the summer-fall season, the prime-irrigation period and the post-irrigation period.

Yield values for the summer-fall season are presented in Table 18. They are derived from the low-flow frequency curves shown in figures 12 and 13 for each of the 1-, 7-, 15- and 30-day low flows for the Delhi and Walsingham gauges, respectively. The yield values for the post-irrigation period are also presented for the one-day and seven-day minimum low flows.

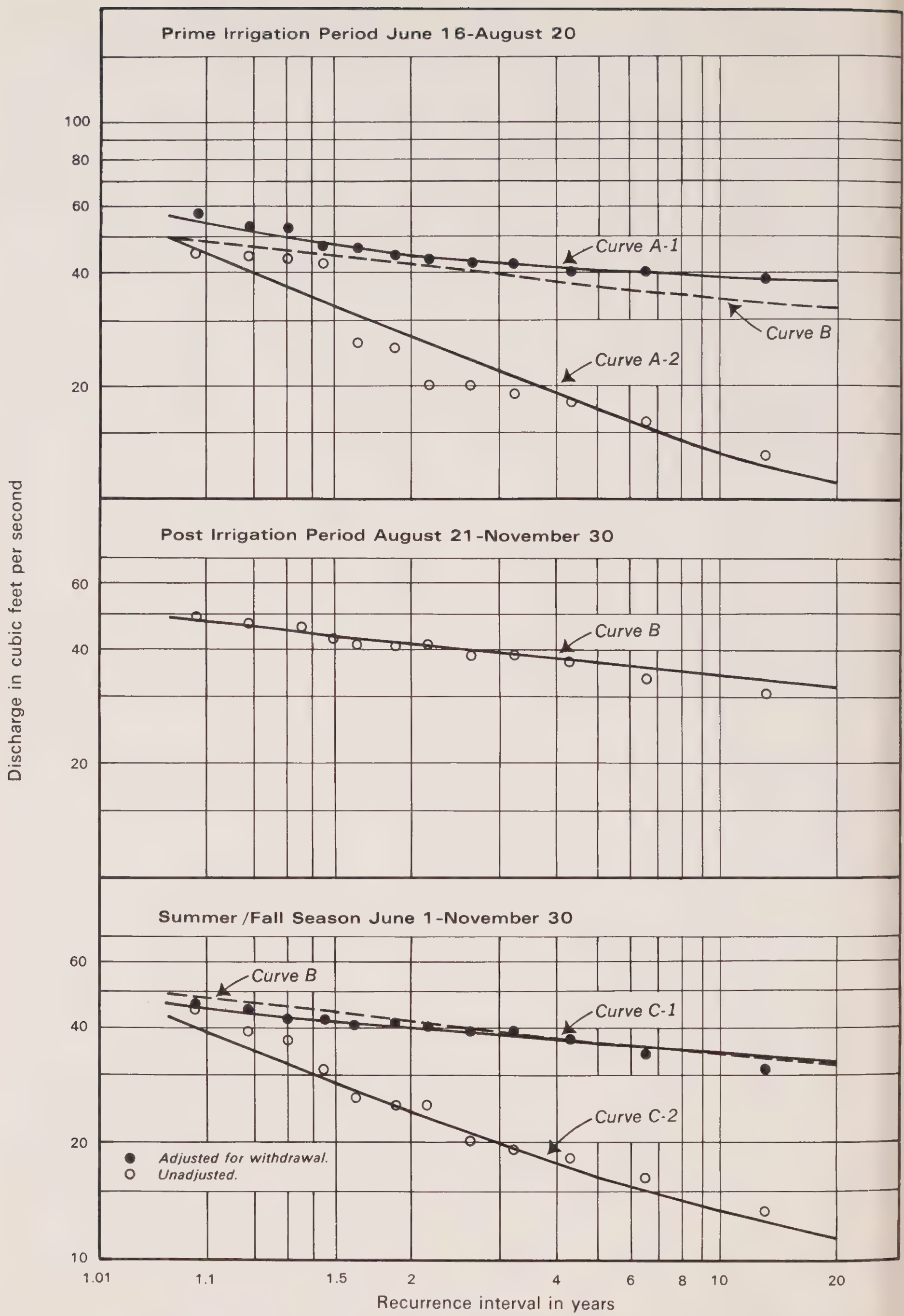


Figure 14. Comparison of frequency curves for seven-day low flows in Big Creek near Delhi, 1956-1967.

Table 18. Low-Flow Yield Characteristics* — Big Creek Basin

Sub-Basin	Drainage Area Square Miles	Average Recurrence Interval	Minimum Yields Per Square Mile											
			Summer-Fall Season (June 1 — November 30)								Post-Irrigation Period (August 21 — November 30)			
			One-Day		Seven-Day		Fifteen-Day		Thirty-Day		One-Day		Seven-Day	
			cfs	mgd	cfs	mgd	cfs	mgd	cfs	mgd	cfs	mgd	cfs	mgd
Big Creek near Delhi	142	Most Probable	0.15	0.08	0.19	0.10	0.24	0.13	0.28	0.15	0.27	0.14	0.30	0.16
		5-Year	0.07	0.04	0.11	0.06	0.17	0.09	0.21	0.11	0.21	0.11	0.25	0.14
		10-Year	0.05	0.02	0.09	0.05	0.15	0.08	0.18	0.10	0.19	0.10	0.24	0.13
Big Creek near Walsingham	221	Most Probable	0.35	0.18	0.36	0.19	0.38	0.20	0.41	0.22	0.40	0.21	0.42	0.22
		5-Year	0.20	0.11	0.22	0.12	0.24	0.13	0.28	0.15	0.30	0.16	0.31	0.17
		10-Year	0.16	0.09	0.17	0.09	0.20	0.11	0.24	0.13	0.27	0.15	0.28	0.15

* Based on recorded discharges 1956-1967

Table 19. Comparison of Low Flow Yield Characteristics*, Big Creek Basin above Delhi Gauging Station, With and Without Adjustments for Water Withdrawals for Irrigation Purposes

Period	Average Recurrence Interval	Minimum Yields Per Square Mile (based on seven-day period)				Water Loss (due to withdrawal)
		Adjusted Flow (to remove irrigation effects)		Recorded Flow (affected by irrigation)		
		cfs	mgd	cfs	mgd	per cent
Prime-Irrigation Period	Most Probable	0.33	0.17	0.22	0.12	33
	5-Year	0.28	0.15	0.12	0.06	57
June 16 – August 20	10-Year	0.27	0.15	0.09	0.05	67
Summer-Fall Season	Most Probable	0.29	0.16	0.19	0.10	34
	5-Year	0.26	0.14	0.11	0.06	58
June 1 – November 30	10-Year	0.24	0.13	0.09	0.05	62

*Based on discharge data 1956-1967

able 20. **Low-Flow Severity Indices, Big Creek Basin**

Gauge Location	Period	Severity Index (10-year most probable low flows)			
		1-Day	7-Day	15-Day	30-Day
Big Creek near Delhi	Summer-Fall Season	0.31	0.48 (0.82)*	0.62	0.65
	Prime-Irrigation Period	–	0.42 (0.85)*	–	–
	Post-Irrigation Period	0.70	0.79	–	–
Big Creek near Walsingham	Summer-Fall Season	0.49	0.48	0.54	0.60
	Prime-Irrigation Period	–	–	–	–
	Post-Irrigation Period	0.70	0.67	–	–

Ratio obtained from streamflow data adjusted to remove irrigation effects.

The results of adjusting recorded flows to remove the deduced effects of vithdrawals for irrigation on the basis of the low-flow frequency curves shown n Figure 14 are summarized in Table 19. This information shows the adverse ·ffects on streamflow produced by the concentrated water withdrawal practices ıbove the Delhi gauge. It is estimated that the amounts of water withdrawn 'or irrigation and not returned to the stream were equal to about one-third of he natural seven-day low flow for the most probable low flow and to about wo-thirds of the natural seven-day low flow for the ten-year recurrence interval.

The low-flow severity indices for both the Delhi and Walsingham gauges ıre presented in Table 20 and are based on the same low-flow frequency :urves as the yield values.

The following observations can be drawn from a comparison of the low-low characteristics:

1. The Big Creek basin above the Delhi streamflow gauging station yields smaller flows per square mile of drainage area than the basin between the Delhi and Walsingham gauging stations during both the summer-fall season and the post-irrigation low-flow period under the existing land and water use patterns and practices.
2. The low-flow severity indices at the Delhi station are larger than those at the Walsingham station, except for those for one-day low flows for both the summer-fall season and post-irrigation period. This is indicative of more stable flows in the basin at the Delhi station than at Walsingham.
3. The seven-day low-flow severity index at the Delhi station derived for the prime-irrigation period is smaller than that derived for the summer-fall season under existing water-use practices.
4. The low-flow yield values of the basin above the Delhi gauge for the prime-irrigation period after adjustment to provide an estimate of natural conditions without the effects of irrigation are all larger than those derived for the post-irrigation periods for comparable seven-day periods, by about seven per cent for the most-probable and 12 per cent for the 5- and 10-year recurrence intervals.

5. The low-flow yield values of the basin above the Delhi gauge for t prime-irrigation period based on recorded discharge at the gauge are significantly smaller than the ones derived for the post-irrigation peri for comparable seven-day periods by about 27, 52 and 63 per cent f the most-probable, 5- and 10-year recurrence intervals, respectively.
6. The low-flow yield and severity indices of the post-irrigation period f the recorded streamflow from the basin above Delhi are all larger th those determined for the prime-irrigation and summer-fall season. T post-irrigation values could be used as a lower limit of the estimat natural yield and severity indices for the prime-irrigation period.

Duration of Flow

Duration curves were prepared of mean monthly streamflows for ea calendar month for Big Creek at the gauging stations near Delhi and ne Walsingham. These curves, in turn, were used to prepare generalized hydr graphs showing mean monthly streamflows for selected durations which in cate the percentages of time during which various discharges were equall or exceeded. Figure 15 shows the mean monthly streamflow conditions f the Delhi station, and Figure 16 for the Walsingham station. The lowest mea monthly flows occur in July rather than in September or October. Under norm conditions, the latter months would likely yield the lowest flows; however, d to the large water withdrawals from the streams, the lowest flows were shift to July.

Duration curves for mean daily flows of Big Creek prepared for the Kelvi Delhi, and Walsingham gauging stations are shown in figures 17, 18 and 1 Duration curves were prepared for both the total annual period and for t June to September period.

These curves and especially those of the June to September period sho the effects of water withdrawal from streamflow. These effects are especial noticeable in curves for the Kelvin and Delhi sites and are less pronounce in those for the Walsingham site. Figure 18 shows two duration curves of t June to September period, one based on long-term data and the other on 196 data. The total discharge during the 1963 period was the lowest on reco and the June to September portion was presented for comparison purposes.

The duration curve for Big Creek near Kelvin for the period 1956-196 was obtained from a curve of relation between records at the Kelvin and Del stations for the common period of record, 1964-1966, and from the Delhi da for the 1956-1966 period.

For comparative purposes, duration curves of streamflow yields from t sub-basins above Kelvin, Delhi and Walsingham are presented in Figure 20. T following observations can be drawn from these curves:

1. The yield per square mile increased for the incremental drainage area between the Kelvin and Delhi, and the Delhi and Walsingham gaugin stations for the smaller yields that occurred from about 20 to 100 pe cent of the time and decreased for the higher yields that occurred les than about 20 per cent of the time.
2. The slope of the duration curve for the basin above Kelvin is muc steeper than either the basin above Delhi or above Walsingham, indica ing different runoff characteristics. The general slope of the duratio curves, especially in their lower sections, can be correlated with th relative percentage of clay or clay loam soils of the respective su basins. The larger the percentage of fine-grained soils, the steeper th slope.

3. The effects of water withdrawn for irrigation are very pronounced for the basins above Kelvin and Delhi.

Components of Streamflow

Big Creek and its tributaries exhibit rather stable flows during low-flow periods which suggest that ground-water discharge plays an important role in the runoff regime. To demonstrate this role, an effort was made to separate the total streamflow at the two main streamflow gauging stations on Big Creek into its two main components; surface or direct runoff and ground-water discharge or base flow.

To this end, hydrographs of base flow were prepared for the Delhi and Walsingham gauges for the period July 1964 to June 1965. Extension of the period was not possible because of the limited availability of data. The separation of the streamflow at these locations into their main components during the period is shown in Figure 21 and Figure 22, respectively. The separation was accomplished through the use of curves of relation between ground-water stage and streamflow, the construction of which is discussed in detail under the ground-water hydrology section of this report. Mean daily values of the total streamflow and base flow were selected from the hydrographs and used to construct duration curves as shown in figures 23 and 24.

Although base flow shows aproximately a four-fold variation through the annual period, the general character of the base-flow hydrographs is one that suggests stable streamflow conditions throughout the summer and fall seasons. The effects of water withdrawals on the base flow and total streamflow are, however, evident. The duration curves, when adjusted for the effects of withdrawal, further indicate the stableness of the flow in the watercourse during low-flow periods.

North Creek

North Creek, a tributary of Big Creek, drains an area of 22.3 square miles. Its headwaters consist mainly of two major branches — the North Branch and the South Branch. The average gradient in these branches is about 19.3 feet per mile. Poor drainage in the headwater areas has been remedied by drainage works. These are shown on Map 2706-8. Near the mouth, the creek has cut a deep valley in which a dam and reservoir were constructed just west of the Town of Delhi. This dam, the Lehman Dam, was completed in 1965 and is operated by the Big Creek Region Conservation Authority. The reservoir provides storage for about 120 acre-feet of water and is used as a source of water for Delhi's muncipal water works system.

Analysis of streamflow in North Creek was restricted to the data collected prior to the construction of the Lehman Dam.

The flow characteristics are portrayed by a hydrograph of mean daily flows for the water year ending in 1964, by frequency curves of high and low flows, by duration curves of mean daily flows and by a hydrograph showing mean monthly streamflow conditions for selected durations which indicate the percentages during which various discharges were equalled or exceeded. These curves are all based upon the streamflow records as collected at the former staff gauge on North Creek.

Variability of Streamflow

The hydrograph of streamflow for the water year ending in 1964 (Figure 25) shows the mean daily flows during the open-water period and estimated

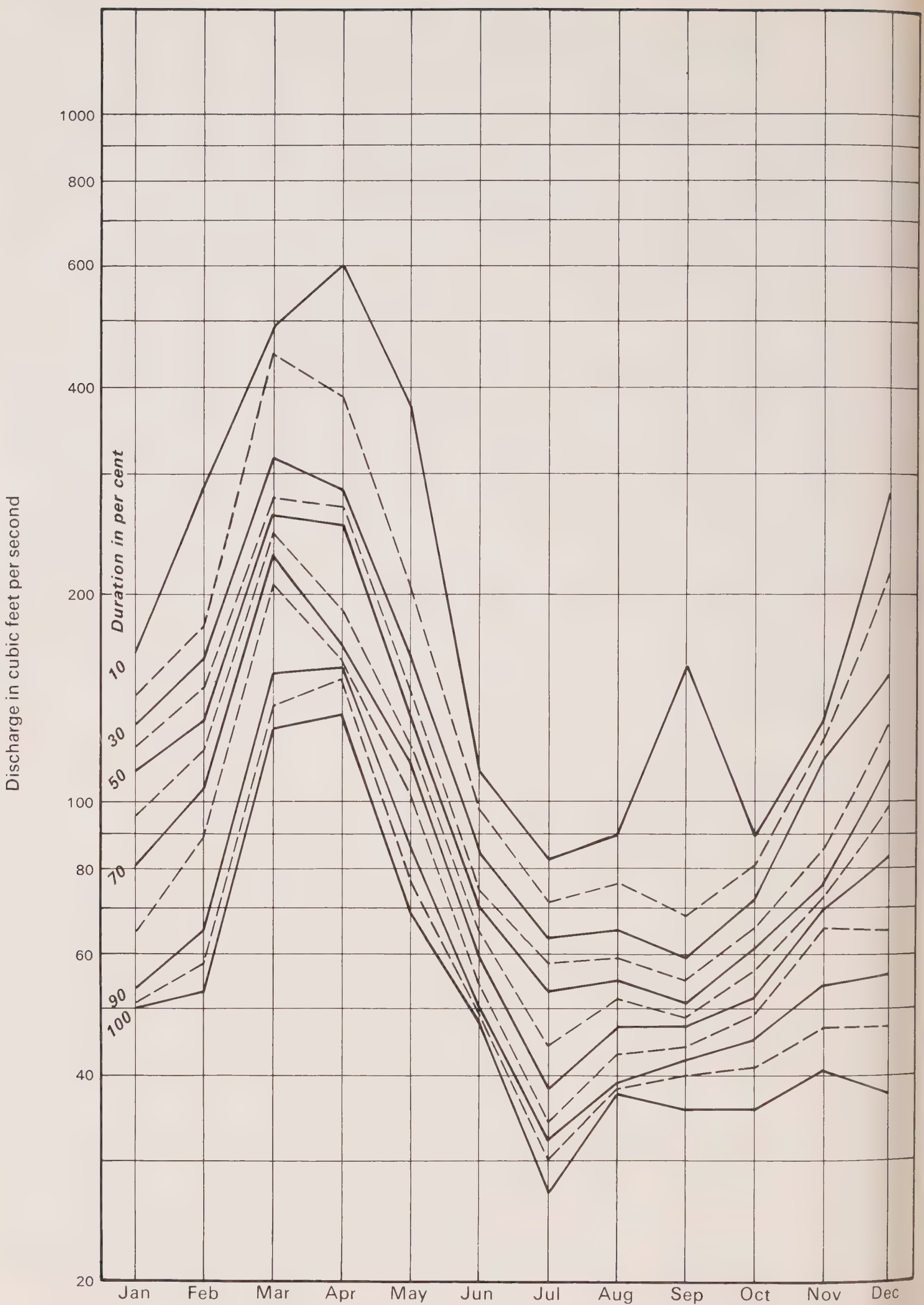
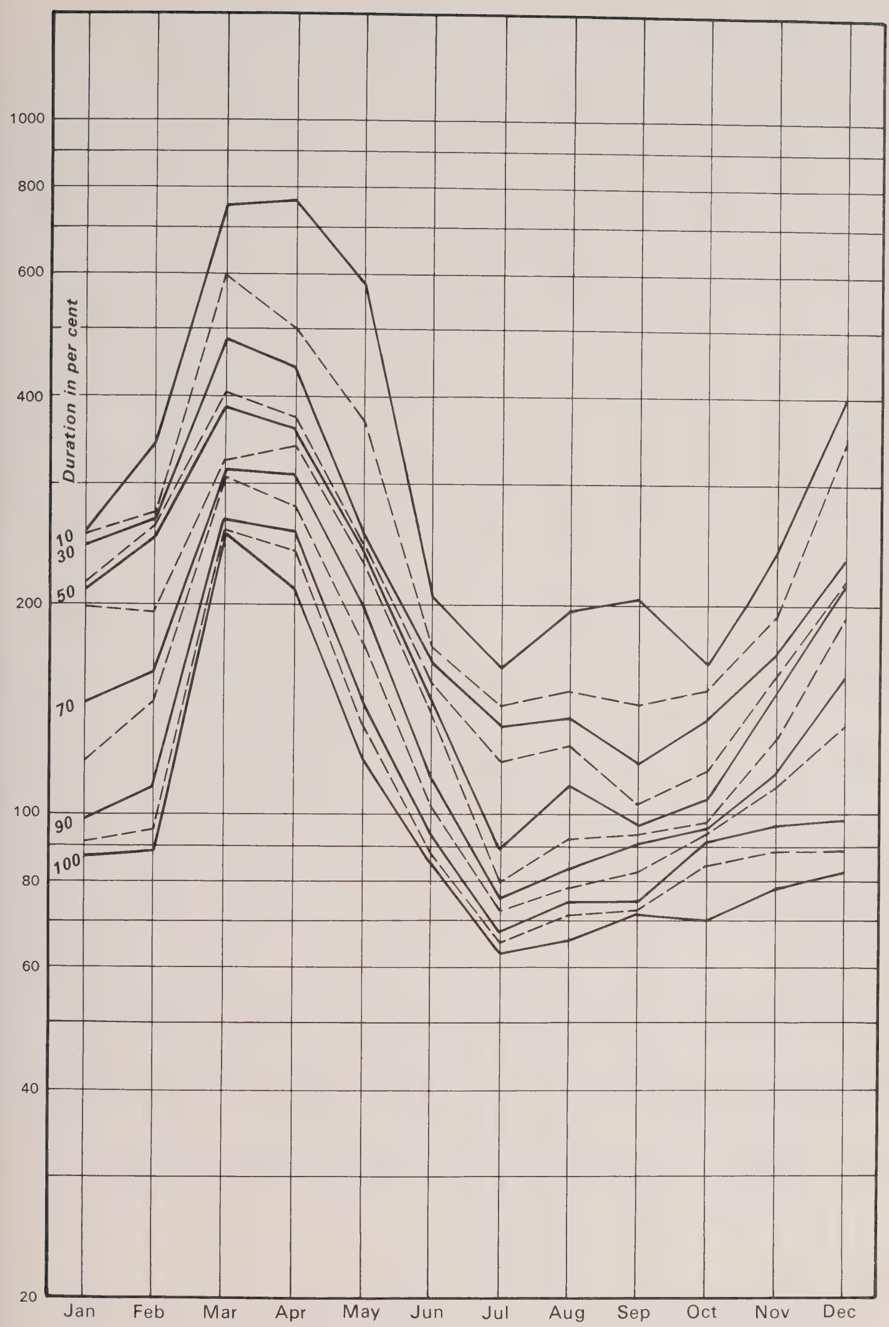


Figure 15. Mean monthly streamflow conditions, Big Creek near Delhi, from duration curves of mean monthly streamflow, 1956-1967.



ure 16. Mean monthly streamflow conditions, Big Creek near Walsingham, from duration curves of mean monthly streamflow, 1956-1967.

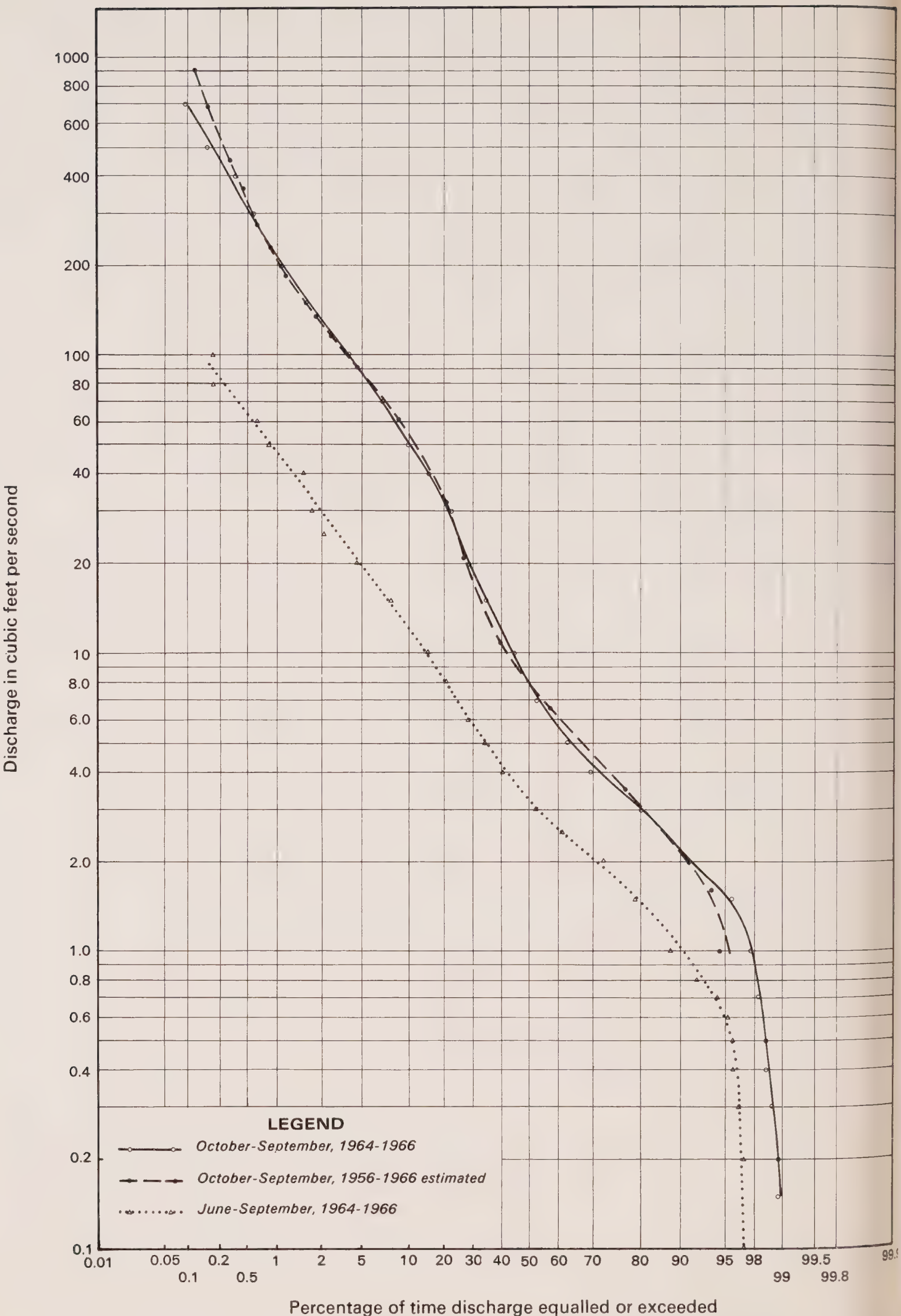


Figure 17. Duration curves for daily flows of Big Creek near Kelvin for selected time periods.

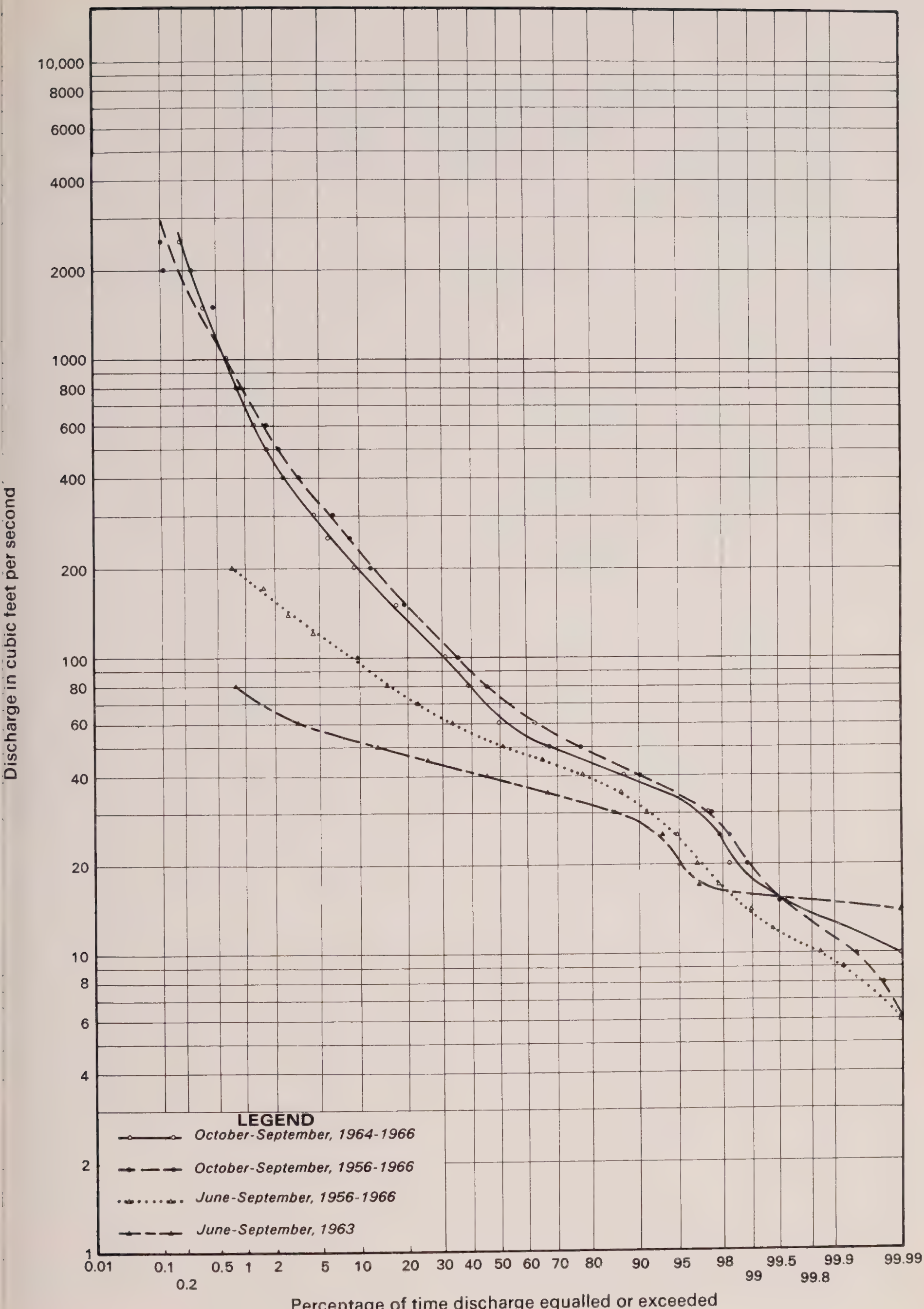


Figure 18. Duration curves for daily flows of Big Creek near Delhi for selected time periods.

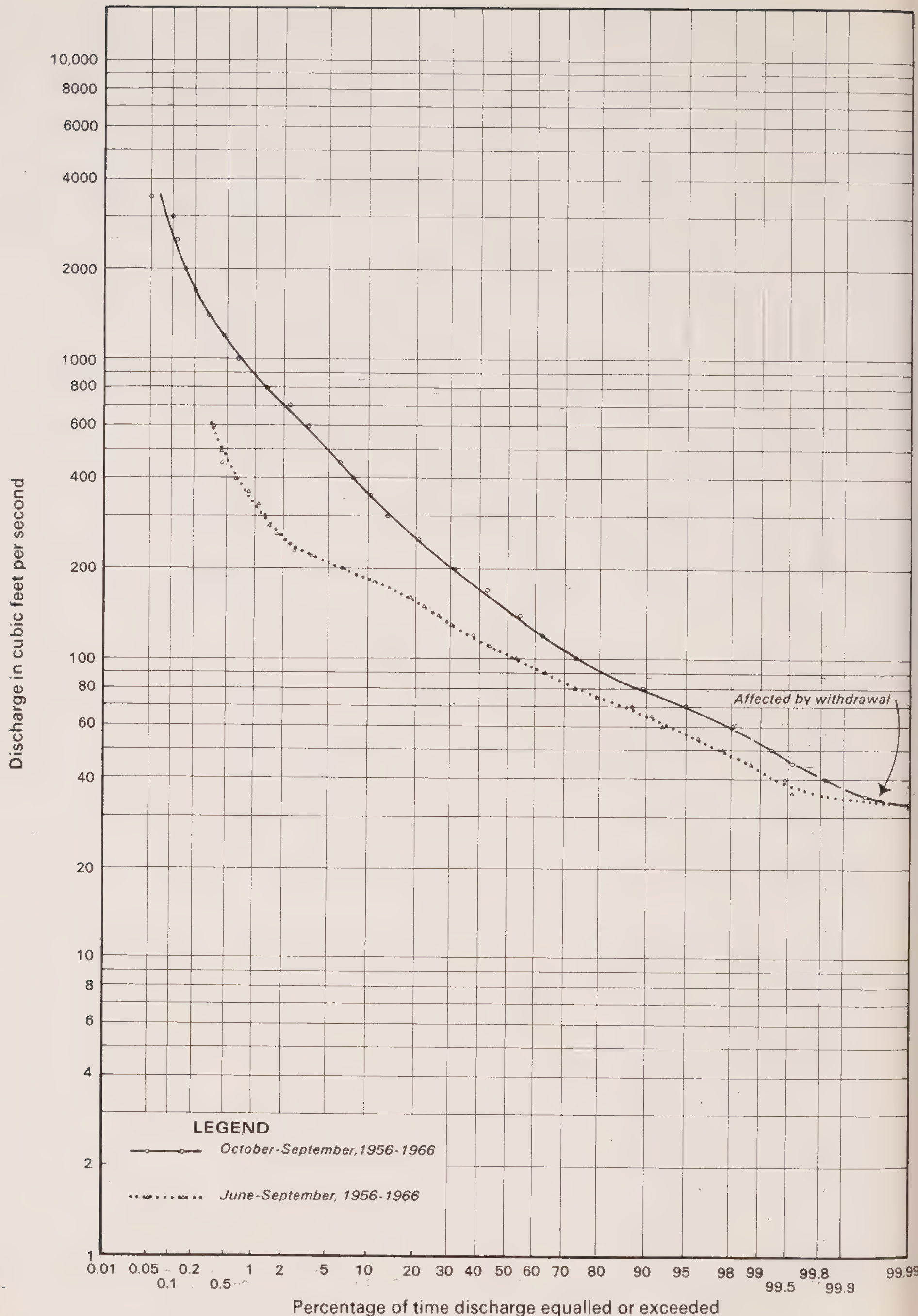


Figure 19. Duration curves for daily flows of Big Creek near Walsingham, 1956-1966.

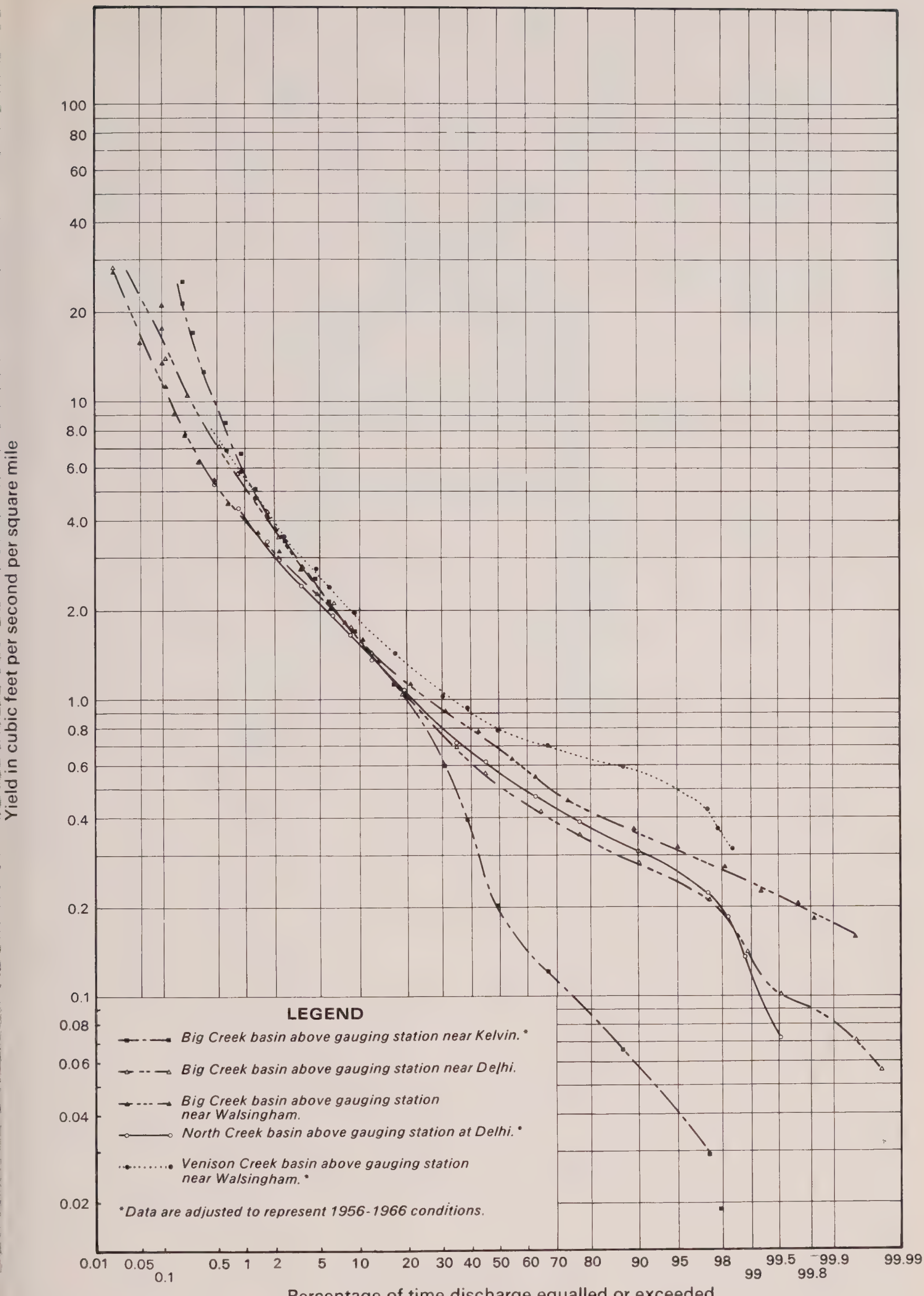


Figure 20. **Comparison of duration curves of daily streamflow-yield characteristics of selected drainage areas, Big Creek basin, 1956-1966.**

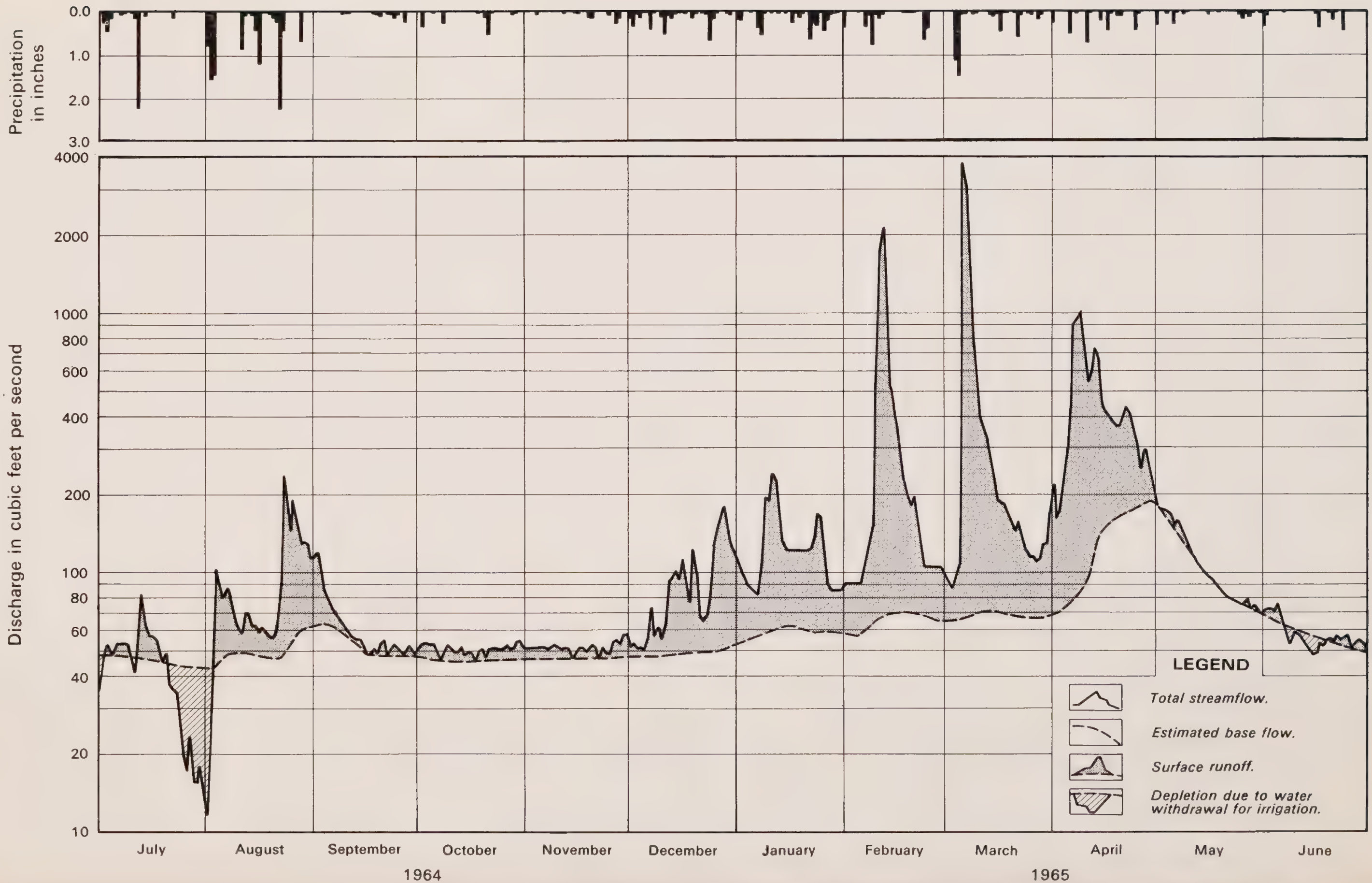


Figure 21. Streamflow hydrographs, Big Creek near Delhi, and precipitation histogram for the annual period July, 1964, to June, 1965.

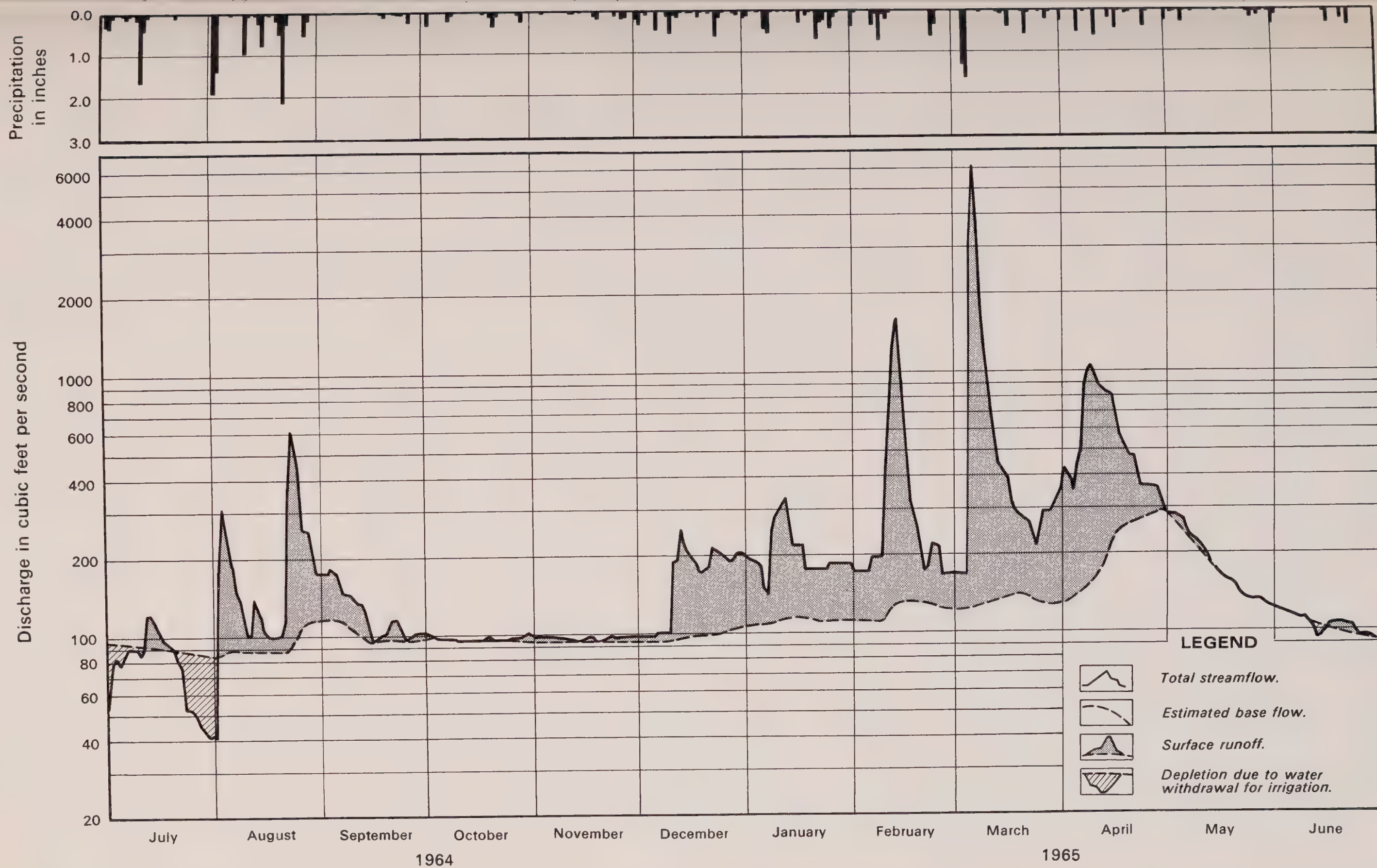


Figure 22. Streamflow hydrographs, Big Creek near Walsingham, and precipitation histogram for the annual period July, 1964, to June,1965.

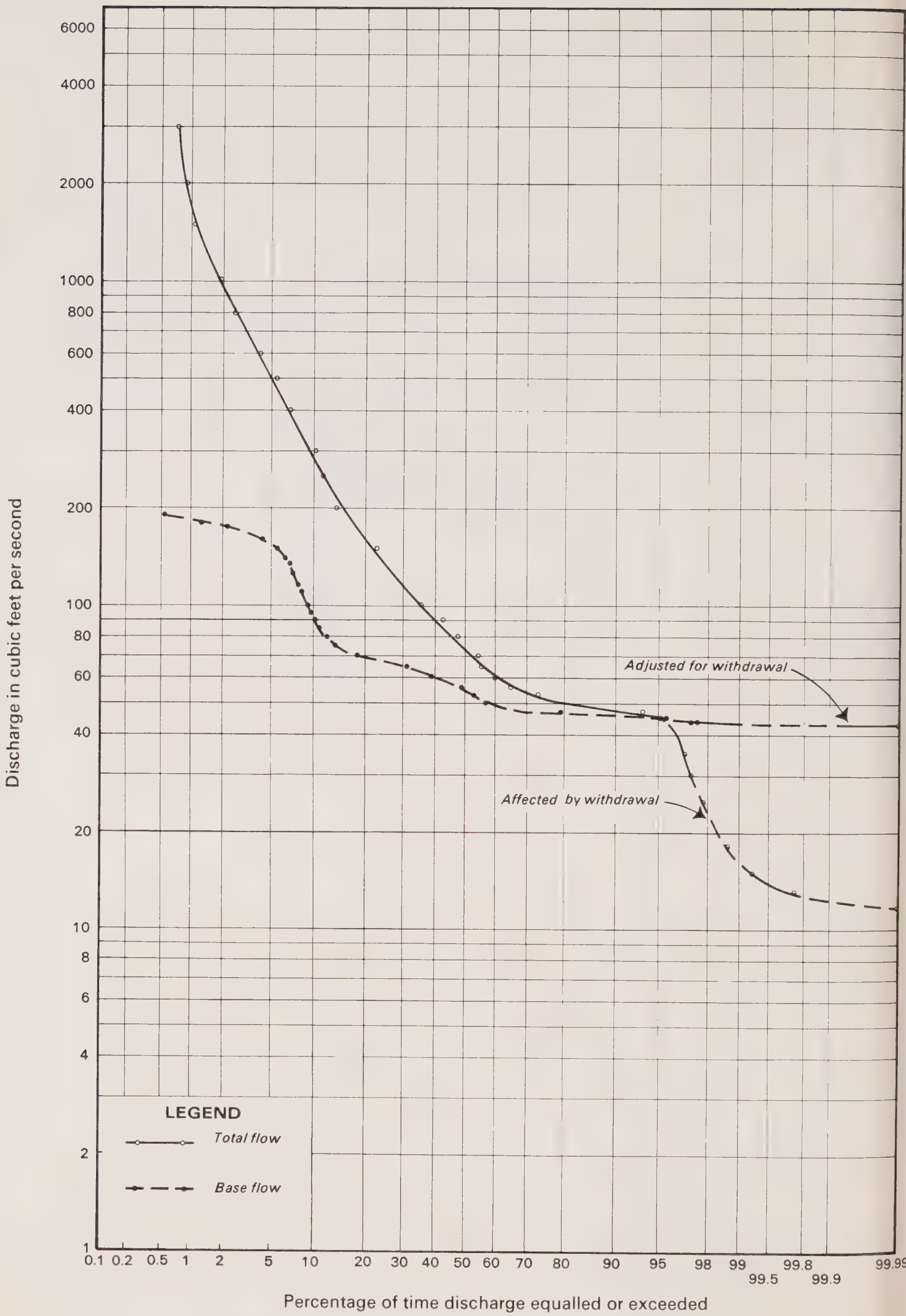


Figure 23. Duration curves for daily flows of Big Creek near Delhi, July 1964-June 1965.

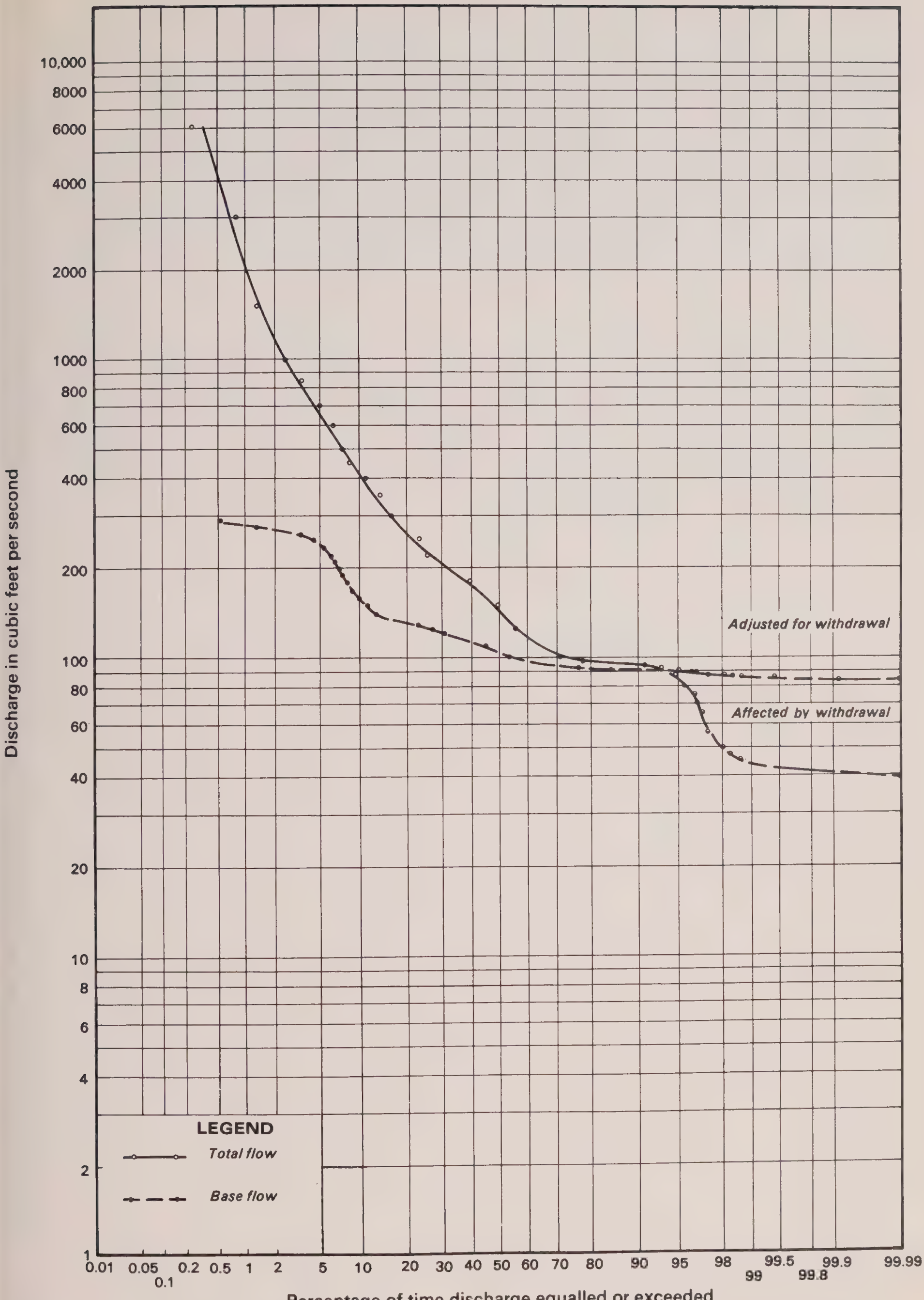


Figure 24. Duration curves for daily flows and base flows, Big Creek near Walsingham, July 1964-June 1965.

Figure 25. Streamflow hydrograph, North Creek at Delhi for water year ending 1964.

multiple-day means during the winter period when ice conditions prevailed in the creek. The streamflow is affected by pumping for the municipal water supply for the Town of Delhi and for crop irrigation purposes. In 1964, the discharge was also affected by the construction of the Lehman Dam. The records show that during the period July 26 to 31, the minimum daily discharge was nil and that the mean daily discharge was nil on July 29 and 30.

The hydrograph shows a similar pattern of rise and fall as was observed in the hydrographs presented for the stations on the main stem of Big Creek (Figure 10). The water-withdrawal effects on the stream's discharge also were pronounced during the last weeks in July and the first day of August, 1964.

High Flows

The taking of streamflow records commenced in October 1954 and, on October 17, 1954, recorded the flood spawned by Hurricane Hazel. This is not the largest one recorded in the basin. A spring freshet produced the largest recorded flood on March 31, 1960. Table 21 lists the annual maximum mean daily discharges of North Creek as recorded at the former Delhi gauging station. Figure 11 presents the high-flow frequency curves based on these discharges, except those for the 1964-1965 and 1965-1966 water years when the Lehman Dam was operating.

Table 21. Maximum Mean Daily Discharges, North Creek at Delhi

(discharges expressed in cubic feet per second)

Water Year	Date		Discharge
1954-55	October	17	511(e)
1955-56	March	7	360
1956-57	April	6	153
1957-58	December	21	127
1958-59	March	6	119
1959-60	March	31	1000
1960-61	April	18	105
1961-62	March	12	239
1962-63	April	20	108
1963-64	August	23	63.0
1964-65	March	6	500(e)
1965-66	February	11	71.0

(e) = estimated discharge

Figure 11 shows the plots of the annual maximum mean daily flows and a theoretical frequency curve fitted to these high-flow data according to the "log Pearson Type III" method. Due to the short period of record the frequency curve may not be very reliable but it indicates the approximate magnitude of high flows or floods at specific recurrence intervals.

Table 22. Minimum Average Discharges and Dates of Occurrence, North Creek at Delhi for Summer-Fall Season, 1955-1965

(discharges, Q, expressed in cubic feet per second; date is starting date of period)

Year	One-Day		Seven-Day		Fifteen-Day		Thirty-Day		Month	
	Q	Date [4]	Q	Date	Q	Date	Q	Date	Q	Date
1955	6	Jul	7	8/ 7	8	8/ 7	8	8/ 7	8	Sep
1956 [1]	10	Jun	11	8/11	12	12/10	12	16/10	12	Oct
1957	7	Aug	9	28/ 7	11	9/ 6	12	12/ 8	14	Jun
1958	3	Aug	5	16/ 8	6	4/ 8	6	26/ 7	6	Aug
1959	2	Aug	3	1/ 8	4	26/ 7	4	18/ 7	5.6	Aug
1960	3.6	Jul	5.4	3/ 9	5.7	25/ 8	6.3	19/ 8	7.2	Sep
1961	4.5	Jul	6.5	26/ 7	7.1	18/ 7	7.6	4/ 9	7.7	Oct
1962	0.0	Jul	1.5	6/ 7	3.9	6/ 7	5.4	29/ 8	5.5	Sep
1963	0.4	Jun	1.6	5/ 7	2.3	26/ 6	3.4	24/ 6	3.9	Jul
1964 [2]	0	Jul	1.1	26/ 7	2.9	18/ 7	5.6	3/ 7	5.8	Jul
1965 [3]	1.8	Jul	4.1	27/ 7	6.3	24/ 7	7.3	4/ 7	7.5	Jul

[1] Discharge records not available for August 22 – September 11.

[2] Discharge affected by the construction of the Lehman Dam upstream of gauge.

[3] Discharge likely affected by the construction and/or operation of the Lehman Dam.

[4] No exact date shown for minimum one-day discharges as some occurred on several dates during month.

Table 23. Minimum Average Discharges and Dates of Occurrence, North Creek at Delhi, for Prime-Irrigation and Post-Irrigation Periods, 1955-1965

(discharges, Q, expressed in cubic feet per second; date is starting date of period)

Year	Prime-Irrigation Period June 16 to August 20				Post-Irrigation Period August 21 to November 30			
	One-Day		Seven-Day		One-Day		Seven-Day	
	Q	Date [4]	Q	Date	Q	Date	Q	Date
1955	6	Jul	7	8/ 7	7	Oct	7	29/ 9
1956 [1]	10	Jun	13	20/ 6	10	Sep Oct Nov	11	8/11
1957	7	Aug	9	28/ 7	10	Aug Sep Oct	11	4/ 9
1958	3	Aug	5	1/ 8	5	Aug	6	21/ 8
1959	2	Aug	3	1/ 8	5	Aug	6	14/ 9
1960	3.6	Jul	6.1	13/ 7	4.5	Sep	5.4	3/ 9
1961	4.5	Jul	6.5	26/ 7	5.2	Oct	6.9	19/10
1962	0	Jul	1.5	6/ 7	2.8	Oct	4.8	3/ 9
1963	0.4	Jun	1.6	5/ 7	4.5	Sep	6.9	18/10
1964 [2]	0.0	Jul	1.1	26/ 7	8.5	Oct	10.1	14/10
1965 [3]	1.8	Jul	4.1	27/ 7	7.4	Sep	8.0	23/ 9

[1] Discharge records not available for August 22 - September 11.

[2] Discharge affected by the construction of the Lehman Dam upstream of gauge.

[3] Discharge likely affected by the construction and operation of the Lehman Dam.

[4] No exact date shown for minimum one-day discharges as some occurred on several dates during month(s).

Low Flows

Table 22 lists the lowest mean discharges of the 1-, 7-, 15-, and 30-day periods and calendar month for the summer-fall season. Table 23 lists the lowest mean discharges of the one- and seven-day periods for the post-irrigation period for the period of record, 1955 to 1965. Frequency curves based on flows for the period 1955 to 1963 are shown in Figure 26; the 1964 and 1965 data were not used due to flow regulation at the Lehman Dam site. Because of the large water withdrawals from North Creek, frequency curves were not drawn for the one- and seven-day periods for the irrigation period. The frequency curves of the one- and seven-day low flows of the post-irrigation period probably present conservative estimates of the discharge in the creek during the prime-irrigation period.

Table 24 presents the estimated low-flow yield characteristics and estimated low-flow severity indices of North Creek. The data in the table are based upon the frequency curves of the post-irrigation period.

Table 24. Estimated Low-Flow Yield Characteristics and Low-Flow Severity Indices, North Creek Basin, for Summer-Fall Season

Basin	Drainage Area (sq. mi.)	Average Recurrence Interval	Minimum Yields Per Sq. Mi.				Severity Index (10-Year most probable low flows)	
			One-Day		Seven-Day			
			cfs	mgd	cfs	mgd	One-Day	Seven-Day
North Creek at Delhi	22.3	Most Probable	0.29	0.16	0.34	0.18		
		5-Year	0.17	0.09	0.23	0.12		
		10-Year	0.14	0.07	0.22	0.12	0.48	0.64

Duration of Flow

Duration curves were prepared of mean monthly flows in North Creek for each calendar month as recorded at the former staff gauge at the creek's mouth. These curves were used to prepare graphs showing the mean monthly streamflow conditions for selected durations giving the percentages of time during which indicated discharges were equalled or exceeded. The results are presented in Figure 27. The lowest mean monthly flows occur in July rather than in September or October. The latter months would likely yield the lowest flows under normal conditions, but large water withdrawals are considered responsible for this shift.

Duration curves of mean daily flows in North Creek for both the annual period and the June to September period are presented in Figure 28. Two duration curves based on annual streamflows are presented; one for the period of record 1956-1965, and the other for the period 1956-1966. The latter one was obtained from a curve of relation between streamflow records at the North Creek and Big Creek gauging stations at and near Delhi, respectively. It shows close agreement with the curve prepared from the staff gauge records. The period 1956-1966 was selected as the common period for comparing streamflow in North Creek with other sub-basins. Figure 20 shows the duration curve of streamflow-yield characteristics for North Creek in addition to the curves for the three existing stations on Big Creek. The figure shows that the duration curve of yield per square mile for North Creek is similar to the curves for Big Creek above Delhi and Walsingham.

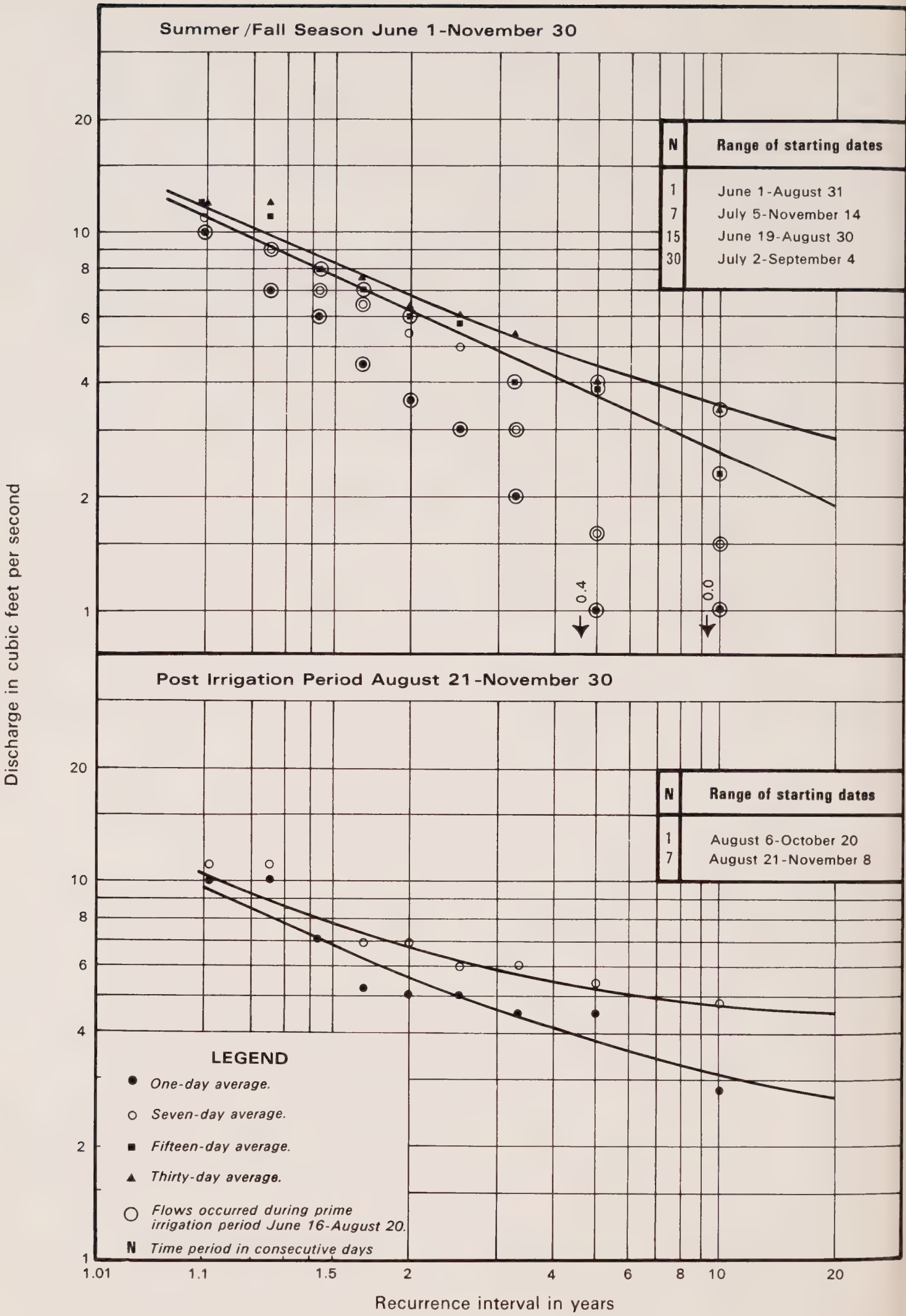


Figure 26. Frequency curves of low flows, North Creek at Delhi, 1955-1963.

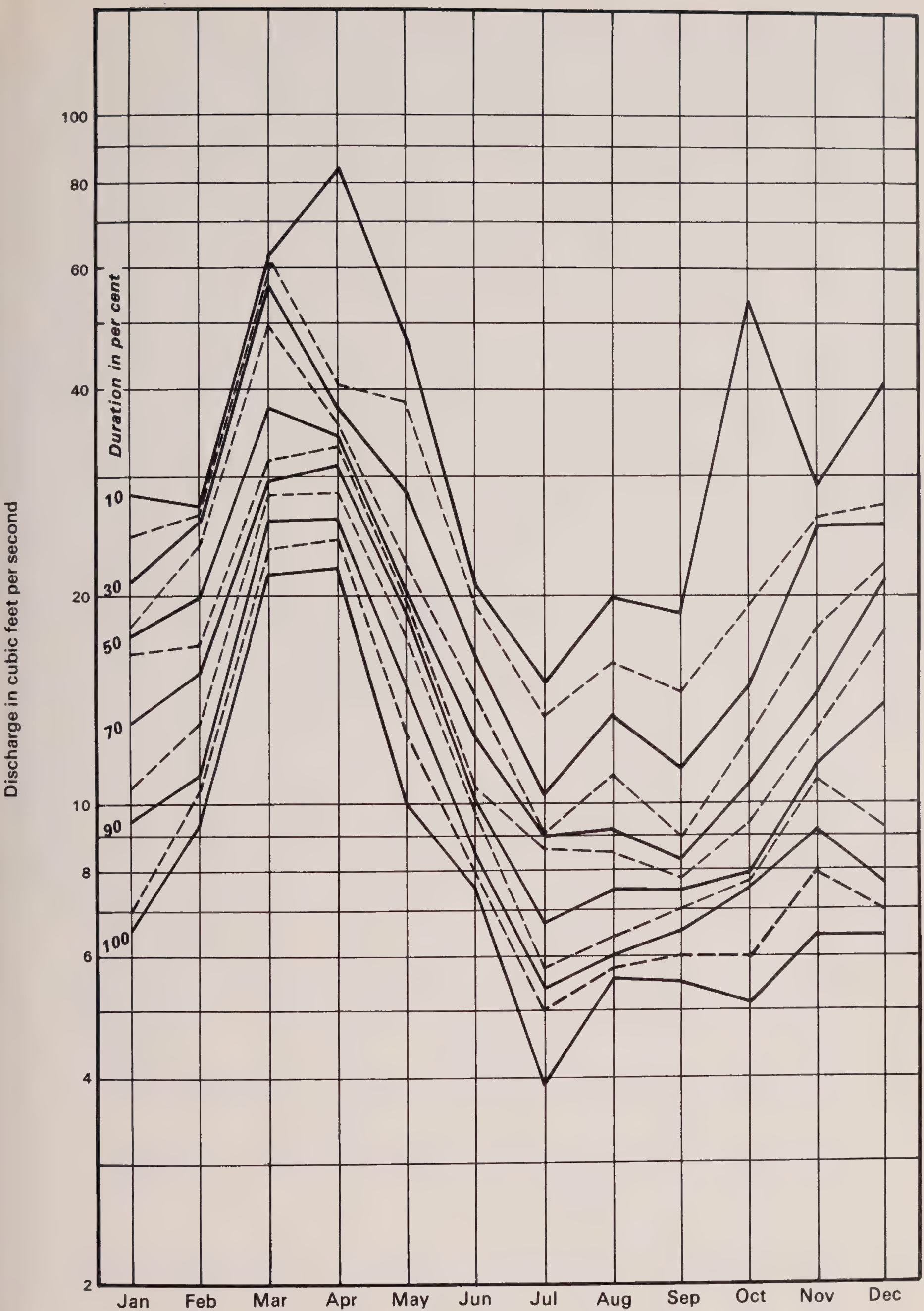


Figure 27. Mean monthly streamflow conditions, North Creek near Delhi, from duration curves of mean monthly streamflow, 1954-1964.

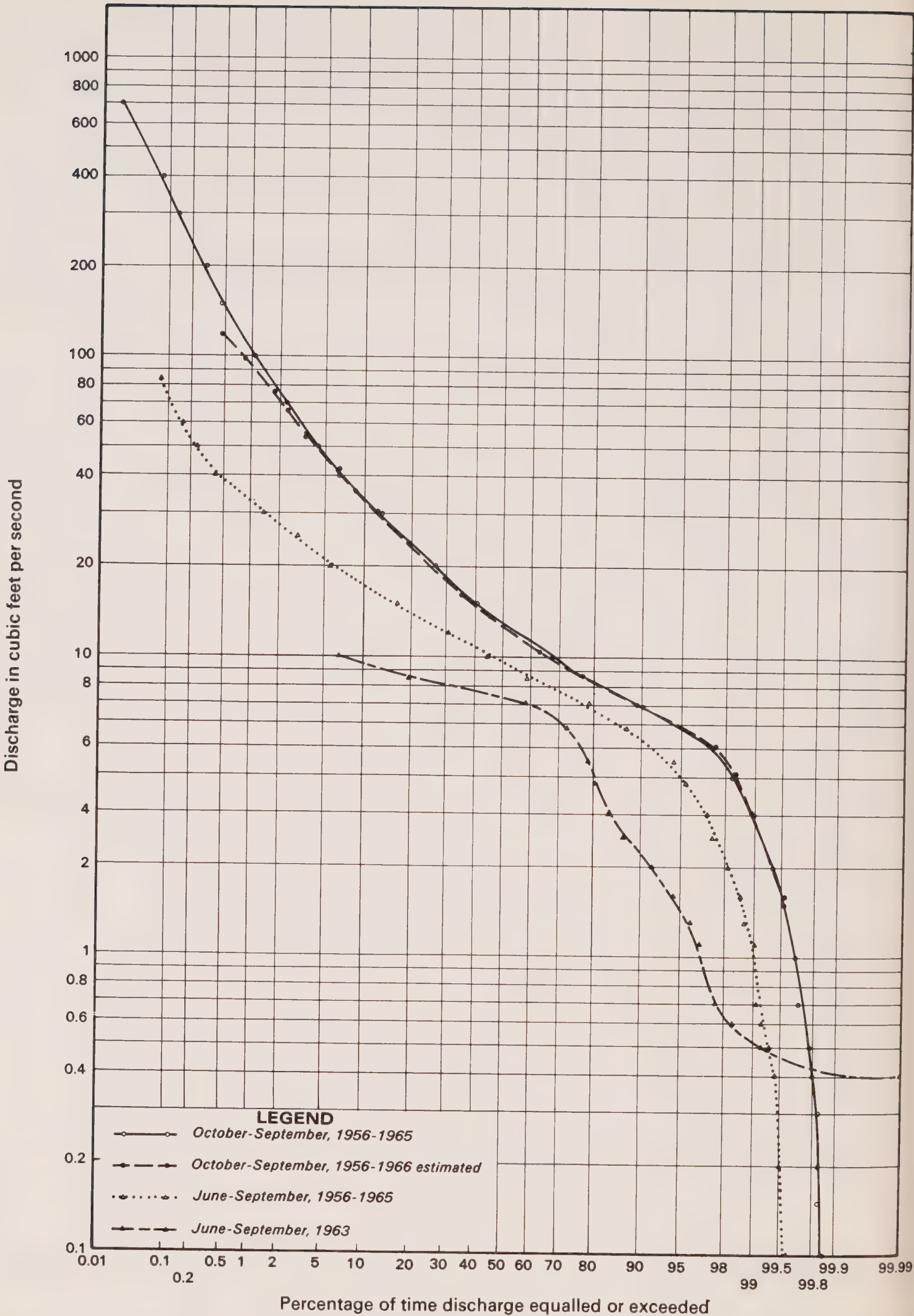


Figure 28. **Duration curves for daily flows of North Creek at Delhi for selected time periods.**

Figure 28 shows two duration curves based on the June to September periods, one for the period 1956-1965 and the other for the water year ending in 1963. There is a marked difference between these curves with flows in 1963 generally being lower than the long-period average except for the extreme lower portion when the lowest one-day flow in 1963 was higher than several daily low flows observed over the long-term period.

Water withdrawals in the basin result in greatly reduced low flows as indicated by the steep slopes in the lower sections of the duration curves. Ordinarily the curves could be expected to show a flattening trend.

Venison Creek

Venison Creek, a tributary of Big Creek, drains an area of 35 square miles. Its headwaters rise about eight miles to the southwest of Delhi, and north of the Middleton-North Walsingham township line. South of this line the creek runs for about five miles in a generally southerly direction. From there it flows in a southeasterly direction for another five miles and joins Big Creek about two miles south of Walsingham. The creek is about 14.2 miles long, has a fall of about 188 feet and has an average gradient of 13.2 feet per mile. The drainage in the headwater area and in the vicinity of Marston has been improved by drainage works on its tributaries. These works are shown on Map 2706-8.

The streamflow characteristics of Venison Creek are shown by a hydrograph of mean daily flows, by tabulated data on mean monthly, high and low flows, and by duration curves of mean daily flows. This information is based upon the streamflow records as collected at the former gauging station near the creek's mouth.

Variability of Streamflow

The hydrograph of mean daily flow for the water year ending in 1964 is presented in Figure 29. During periods of high flow the discharge measurements for Venison Creek are affected by backwater effects from Big Creek. During the summer period, the discharge is affected by water withdrawn for irrigation, resulting in lower than natural streamflow during this period. The records show that during the 1964 summer period the flow during the period July 21 to August 1 was adversely affected by irrigation practices in the basin.

The mean monthly flows of Venison Creek for the period 1963-1966 are presented in Table 25 and show the variability in these flows.

Table 25. Mean Monthly Discharges, Venison Creek near Walsingham, Big Creek Basin, 1963-1966

(discharges expressed in cubic feet per second)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1963-1964	21.1	21.9	23.3	27.2	24.3	44.3	47.3	37.6	22.4	19.2	34.4	25.6
1964-1965	23.1	23.1	45.4	53.3	96.4	144	84.8	39.0	29.4	22.3	26.5	29.4
1965-1966	35.0	37.2	47.5	28.3	56.3	89.2	55.4	42.9	30.2	15.3	20.0	19.6

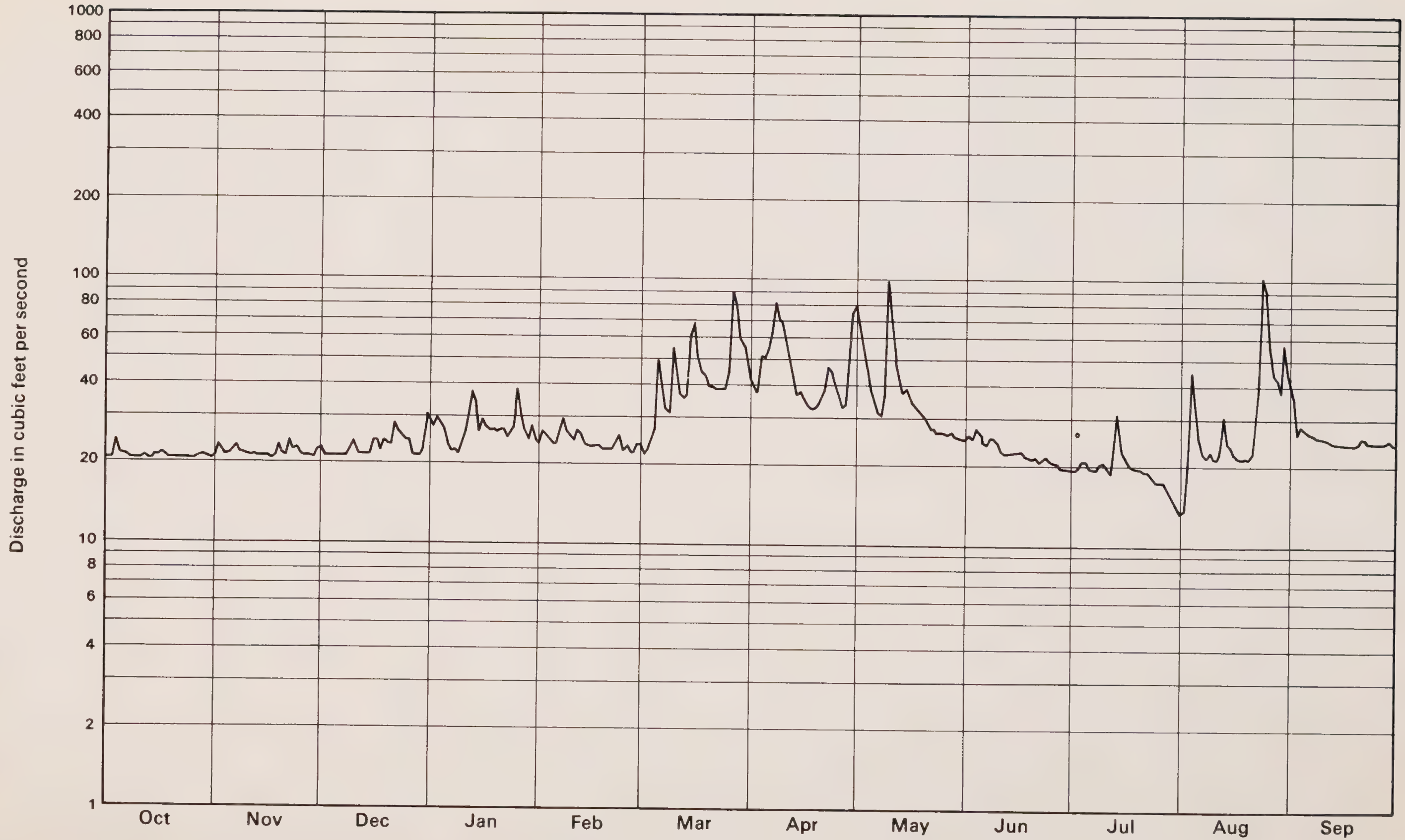


Figure 29. **Streamflow hydrograph, Venison Creek near Walsingham for water year ending 1964.**

High Flows

Due to the short period of record, limited information is available about the magnitude of floods which have occurred in this basin. Table 11 contains maximum annual flood data on Venison Creek for the period 1963-1966. The highest estimated mean daily discharge of 1,580 cfs will likely have an average recurrence interval of about eight years or larger.

Low Flows

Table 26 lists the lowest mean discharge of the 1-, 7-, 15- and 30-day periods and calendar months for the summer-fall season, 1964-1966. Most of these selected low flows occurred during the prime-irrigation period, June 16-August 20. These flows are the remainder of the natural flow not used for irrigative purposes and are of relatively high magnitude. The yield values for the seven-day lowest flow periods range from about 0.25 to 0.62 cfs per square mile and are much larger than those in other sub-basins terminating at the other stream-flow gauging stations in the Big Creek basin during the same time period. It would appear, therefore, that ground-water discharge plays a significant role in sustaining the streamflow in Venison Creek.

Table 26. Minimum Average Discharges and Dates of Occurrence, Venison Creek near Walsingham, for Summer-Fall Season, 1964-1966

(discharges, Q, expressed in cubic feet per second, date is starting date of period)

Year	One-Day		Seven-Day		Fifteen-Day		Thirty-Day		Month	
	Q	Date*	Q	Date	Q	Date	Q	Date	Q	Date
1964	13.2	Jul	14.9	26/ 7	16.8	18/ 7	19.0	4/ 7	19.2	Jul
1965	13.4	Jul	15.6	27/ 7	17.2	19/ 7	21.3	5/ 7	22.3	Jul
1966	8.2	Sep	9.3	21/ 7	11.2	13/ 7	14.3	9/ 7	15.3	Jul

* No exact date shown for minimum one-day discharges as some occurred on several dates during month.

Duration of Flow

Duration curves for mean daily flows of Venison Creek for both the annual period and the June to September period are presented in Figure 30. Two duration curves are presented for the annual period, one based on the period of record 1964-1966, and the other estimated for the period 1956-1966. The latter was obtained from a curve of relation between records of Venison Creek and Big Creek near Delhi. The duration curve of mean daily discharge for the June to September period is based upon the period 1964-1966. All of these curves show a distinct dip in their lower portions which is caused by water withdrawal from the basin for irrigative purposes. Values in this section of the curves occurred during the summer period.

The duration curve for the period 1956-1966 is presented also in Figure 20, where the discharge is expressed in cfs per square mile. Duration curves for other selected drainage areas in Big Creek basin for the same period are also shown on this figure. Comparison of the duration curves indicates that the

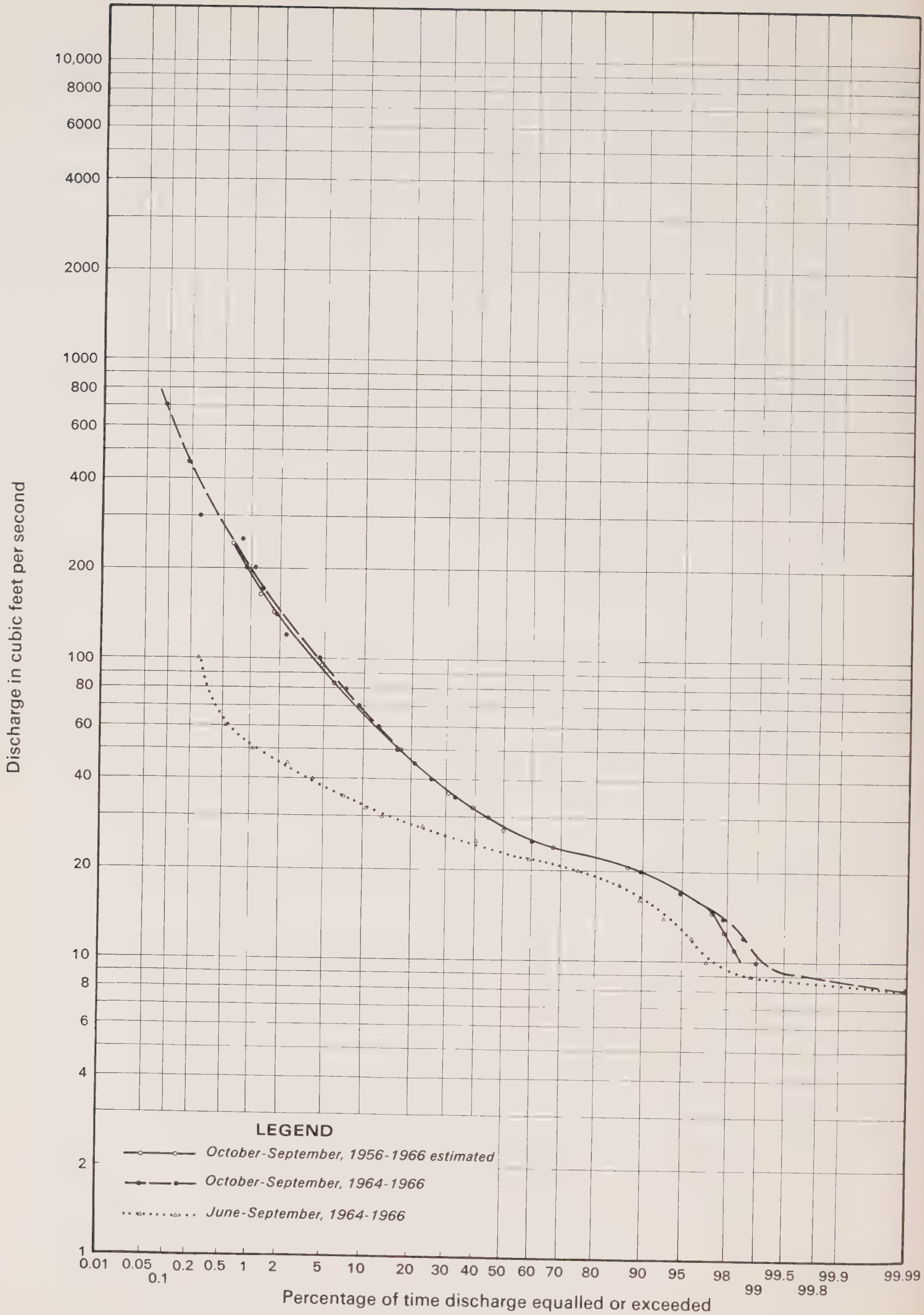


Figure 30. Duration curves for daily flows of Venison Creek near Walsingham for selected time periods.

yield per square mile in the Venison Creek drainage area is higher than the yields from other selected areas in the Big Creek basin. The general slope of the duration curve for Venison Creek in the middle and lower ranges is the flattest one of those presented, indicating that the creek has the lowest recession rate of all the selected drainage areas, thus reflecting more stable base-flow conditions.

Low Flow Comparison

In the Big Creek basin large-scale withdrawals of water from both the streams and from ground-water sources for irrigation generally coincide with low-flow conditions in the streams and affect adversely the streamflow. Reductions of up to 70 per cent were calculated in the natural mean daily flow at the gauging station on Big Creek near Delhi during the summer of 1964 (Figure 21), and instantaneous flows were even further reduced. To acquire an appreciation of the variability of flows between natural streamflow at a specific probability level and streamflow during the irrigation period in the basin, the natural, most-probable, minimum seven-day average flow under open-water conditions was estimated at a number of locations on streams in the basin and compared to the lowest recorded flow at each of these locations. The results are shown in Figure 31.

The selection of the probability level was quite arbitrary. It was felt that the most-probable level, selected to be at a recurrence interval of 1.58 years, would indicate average conditions and could be a guide for any water-use management scheme for the whole basin.

The seven-day flow unit was selected as it best represents short-term streamflow conditions and will be less affected by any possible taking into storage or blockage of flow at any site in the basin than the one-day flow.

The lowest recorded flow at each site was obtained from a limited number of actual flow measurements, except at sites at which streamflow gauging stations are or were in operation. From 2 to 12 individual measurements were taken at selected locations during the open-water periods from June 1962 to August 1968 but mainly in 1964. The measurements were taken under base-flow conditions and most of the flows were likely affected by irrigation, but some may not have been.

The estimates of the natural, most-probable, minimum seven-day average flow at each of the locations were determined as follows:

1. The measured flows collected under base-flow conditions at each of these locations were compared to the same-day mean flow at a nearby long-term gauging station or stations and ratios of flow established between them.
2. The most probable flow values were read from the frequency curves of minimum seven-day average low flows during the post-irrigation period, as shown in figures 12, 13, and 26, for the flows of Big Creek at the Delhi and Walsingham gauges and of North Creek at Delhi.
3. The ratios determined under (1) were applied to the most probable flow values extracted from the frequency curves under (2) resulting in estimates of the most probable, minimum seven-day average flow at the selected locations in the basin.

The "seven-day" low flow values as shown in Figure 31 may indicate lower flows than would naturally occur during the "prime-irrigation" period. It is estimated that the natural seven-day flows during the prime-irrigation period could be about ten per cent higher than the values shown.

Due to the relatively low recession rate of streamflow during base-flow conditions in the major portion of the basin, it is estimated that the minimum

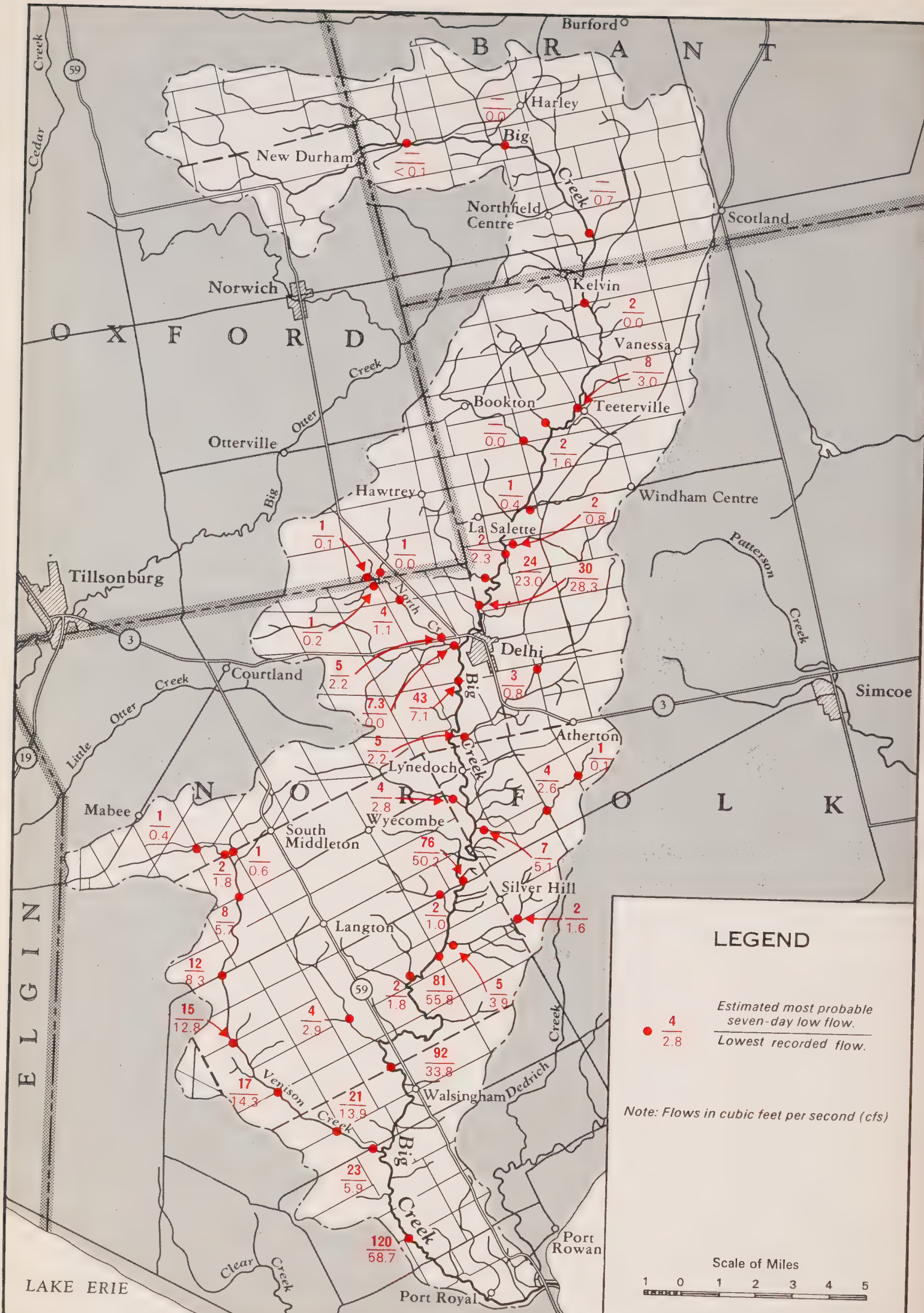


Figure 31. Estimated most probable seven-day low flows under non-irrigative conditions and lowest recorded flows, Big Creek basin.

one-day low flows under natural conditions will be smaller than the corresponding natural "seven-day" flows by only about five to ten per cent for the basin below the Kelvin streamflow gauging station.

The lowest recorded flows cannot be compared to one another as they were taken at different times, days, months, or even years. These flows likely do not represent the worst streamflow conditions at these locations. It is possible that many of the tributaries to Big Creek have been dry at times in the past although available records may indicate low flows as shown on Figure 31. Big Creek itself above the Kelvin gauge has no flow, as indicated by the automatic gauge near Kelvin.

Ground Water

Ground water is generally defined as subsurface water that occurs in the zone of saturation below the water-table. There is an interrelationship between ground water and other forms of subsurface water, but because of the importance of ground water for water supply purposes its availability, movement and replenishment are primary considerations of this section.

Source and Occurrence

All subsurface waters in the basin are considered as having their origin in precipitation that falls in the basin. In certain circumstances, subsurface waters may move across the boundaries of adjacent basins, but this was not considered significant in the Big Creek Basin because of hydrologic evidence.

Subsurface waters occur in three zones below the land surface (Figure 32): the zone of aeration which occurs above the water-table and contains "suspended water" (vadose water); the zone of saturation which occurs below the water-table and contains "ground water" (phreatic water); and the zone of impermeable rock which is below the zone of saturation and contains only internal water.

As water infiltrates into the ground, it first passes through the zone of aeration. In this zone some of the water is retained. Most of the time all the voids and pore spaces between the grains are not filled with water, rather, the individual grains are only wetted. The water in this zone is further sub-divided into soil water or moisture, pellicular and gravitational water and capillary water above the water table. Generally, flow in the zone is vertically downward but certain geologic conditions may cause the water to move and discharge laterally. The lateral movement is called interflow.

Water that enters the zone of saturation fills all openings or pore spaces in the earth's formations. The upper surface of this zone is called the water-table and it fluctuates in proportion to the amount of water that enters and leaves the zone of saturation. Water in this zone is called ground water. Ground-water movement in this zone takes place in accordance with the total fluid potential, a function of total head and gravity, and the water-transmitting ability of the formations. The more permeable formations in the zone of saturation constitute important storage and transmission areas for ground water and are commonly referred to as ground-water reservoirs or aquifers. The water-bearing and yielding properties of the various formations in the zone of saturation in the Big Creek basin are discussed in detail below.

The zone of impermeable rock receives no water from the surface and is not affected by the hydrologic cycle.

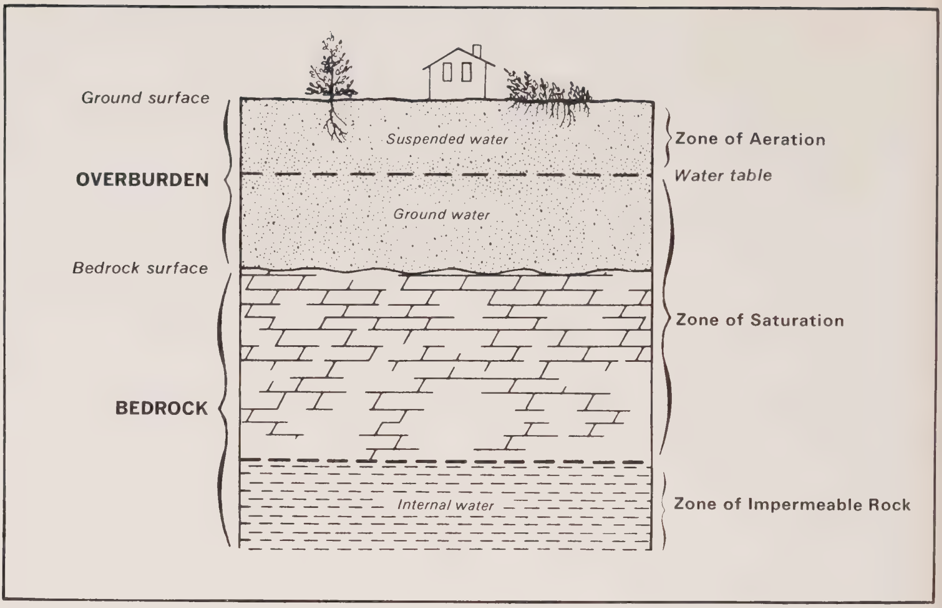


Figure 32. Generalized section of the earth's crust showing zones of subsurface waters.

Availability of Ground Water to Wells

Ground water occurs in two different hydrogeologic formations. Aquifers are permeable formations that are capable of transmitting water through the interconnected pore spaces in the formation and yielding it to wells readily. Sand and gravel deposits are good examples. A formation that holds water but does not readily transmit or yield water to wells is known as an aquiclude. Silts and clays are examples. A geologic formation that neither contains nor transmits water is known as an aquifuge. Igneous rocks at depth generally fit this category.

Map 2706-5 shows the availability of ground water in the basin, based on geologic logs and hydraulic properties of the various formations or deposits as derived from water-well records filed with the OWRC. The locations of water wells in the basin are shown on Map 2706-1. Records for selected wells are shown in Appendix A. No attempt was made to define the perennial yield characteristics of any of the formations or aquifers. Rather, it shows the quantity of water that might be developed and obtained from a single well structure for an unspecified period of time.

The most obvious observations from Map 2706-5 are that, in spite of the abundance of saturated materials in the basin, yields to a single well over a large portion of the basin can generally be expected to be less than 50 gpm, with yields in much of this area being less than 10 gpm. Substantial areas exist where difficulties will be encountered in developing sufficient quantities of water for low-capacity domestic wells. The area near the mouth of the basin is a prime example.

Water in the Bedrock Formations

Ground water occurs mainly in joint fractures, fissures, bedding planes and solution channels in bedrock formations in the Big Creek basin. Internal pore spaces in the rock units are believed to be very small in most of the formations and are therefore of negligible importance. The occurrence and distribution of the secondary porosity appears to be quite variable throughout the basin, with the result that the occurrence of ground water and the volume available to wells is highly variable. Well data indicate that potable ground water occurs mainly in the upper portions of the bedrock and that, except for the northern part of the basin such as in the areas near Windham Centre, Vanessa, Scotland, Kelvin and Beaconsfield yields are generally low, probably less than 10 gpm. Water-bearing zones have been encountered at depths as great as 1000 feet into the bedrock, but, although the yields may be substantial, the water quality at depth is usually unsatisfactory because of excessive mineral content.

The Delaware Formation is a limestone that underlies a large portion of the basin. Logs for wells that penetrate the formation show that the occurrence of fresh water is sporadic and only in the upper 10 feet or less where a direct connection with water from the overburden probably exists. Yields are generally low but possibly adequate for domestic purposes. The occurrence of highly-mineralized water near the bedrock surface is not uncommon.

There is no evidence to indicate that the bedrock formations that underlie the Delaware Formation contain any fresh water zones. Water-bearing zones occur at several depths up to 1000 feet in the bedrock and often appear to coincide with geologic contacts between formations. The disconformity between the Devonian and Silurian rock systems appears to be such a zone and may derive its transmitting characteristics from solutioning along the contact or a permeable zone in the Oriskany sandstone. Yields may exceed 100 gpm from these zones as indicated by free-flowing wells (wells A and B, Figure 39) near Lynedock and Silver Hill but the water quality is unsuitable for most purposes.

Except for parts of the Bois Blanc Formation, bedrock formations that subcrop in the northern portion of the basin generally exhibit low to medium yield characteristics. Records show that yields up to 50 gpm may be obtained from wells at local sites but that the general yield may be substantially less. The occurrence of mineralized water is fairly common in some areas; even near the bedrock surface where fresh-water zones occur, they are generally at shallow depth in the bedrock. The deeper zones contain poor quality water.

Wells that penetrate the Bois Blanc Formation in the Vanessa-Windham Centre area are reported to yield 12 to 250 gpm at depths up to 50 feet into the bedrock. Wells pumped at the lower rates might yield greater quantities with further development. The water-yielding characteristics of the Bois Blanc Formation in other areas are generally not as high, suggesting that some other factor may contribute to the high yields. A test well drilled in the area during the survey showed water-bearing gravels present over the rock which may be hydraulically connected to the rock zones and provide the extra ground-water storage. Weathering of the bedrock surface and the presence of a disconformity between the Bois Blanc Formation and the Bass Island Formation at shallow depth in the rock probably contribute to the permeability of the rock formation. One well in the area (Well No. 155) probably penetrated the Salina Formation as mineralized water was obtained in addition to the higher, better-quality water.

Water in the Overburden Deposits

Ground water occurs in the pore spaces of all overburden deposits in the basin except where the deposits are above the water-table. Overburden materials vary in composition and grain size from clay to gravel. The finer-grained materials contain the highest porosities and therefore store the largest quantities of water per unit volume, but the coarser-grained sand and gravel deposits possess the better permeability characteristics and yield water more readily to wells or other withdrawal structures. The saturated, coarser-grained materials are therefore the most important sources of ground water for water-supply purposes. The finer-grained materials do not readily release water for withdrawal but, because of their large storage capacities and slow, steady rates of release, are probably an important factor in streamflow maintenance.

Morainic deposits—The morainic deposits in the basin consist of till which generally contains large quantities of clay. The result is that low water-yielding characteristics are inherent and provide problems in well development. Wells attempted in the till in the extreme southern part of the basin are inadequate even for domestic purposes. Wells along the moraine ridges generally have to be extended into other deposits. The till on the plain between the St. Thomas and Tillsonburg moraines has been reworked and includes sands which provide more favourable characteristics.

Fine-grained lacustrine deposits—The basin contains a preponderance of fine-grained lacustrine deposits throughout its length. Drill logs show that the thick sequences of clays, silts and fine sands are saturated and therefore represent a large volume of ground water in storage. Development of wells has met with very limited success only in some of the thicker fine sand sequences. The importance of these deposits to streamflow, however, is apparent in the numerous seepages of ground water along deeply dissected stream valleys south of Delhi.

Shallow-water lacustrine and fluvial deposits—These deposits cover approximately 75% of the basin area and, because of their ability to store and release water to wells, are the single most important hydrogeologic unit in the basin. Although local variations exist, the deposits generally consist of fine- to medium-grained sand. Grain-size limitations in addition to minimal saturated thicknesses of 20 feet or less, act to the detriment of the deposit as a source of water for individual high-capacity wells. Capacities of up to 10 gpm are common from a single structure in the area south of Delhi where the surface is better drained and the saturated thickness of the deposit thereby reduced. Better water-yielding characteristics are displayed in the deposits that occur along spillways between the morainic ridges west and north of Delhi. The possible containing effect of the moraines and the presence of coarse sands and, occasionally, gravels at depth provide more suitable hydrogeologic conditions for the storage of ground water and development of large quantities of water (50 gpm or more) from single wells. The most significant areas occur east of Harley and northwest of Delhi, where saturated sands and gravels, at depth, parallel the possible westward extension of the Paris moraine. Additional, favourable deposits may be present between the twin strands of the Paris moraine west of Delhi.

Beach deposits—Beach deposits of sand and gravel occur mainly between Delhi and Windham Centre and are closely associated with kame deposits on which they have been superimposed. All the deposits observed were above the water-table and therefore, of no value as sources of ground water. Small deposits near Summerville, Courtland and Guysborough are closely associated with spillway deposits and may possess favourable water-yielding characteristics.

Kame and glacial outwash deposits—These deposits of sand and gravel occur mainly along and between the twin strands of the Paris moraine from Delhi to Burford. The deposits are highly permeable but are topographically situated at elevations where almost complete drainage is possible, thus reducing their value for ground-water supply purposes. Portions of the deposits are saturated north of Scotland and constitute a major source of ground water. Test drilling of the deposit southeast of Delhi encountered less than 30 feet of saturated material, thereby limiting its value for high-capacity purposes.

Alluvial and swamp deposits—Alluvial deposits along flood plains are thin and often well-drained and yield only small quantities of water to wells. Swamp deposits have no value for water-supply purposes other than wildlife watering.

Movement, Recharge and Discharge

The zone of saturation is a dynamic system in which ground water is in constant motion, the rate of movement depending on the hydraulic gradient and the permeability characteristics of the materials. Recharge of the zone by precipitation causes changes in the water-table and hydraulic gradients thereby causing changes in the rate of discharge of ground water. Ground water discharges directly to streams as base flow and sustains streamflow during dry weather periods. It also discharges as springs along hillsides and streambanks and in swamps which eventually drain to streams. The base flow in streams is thus a measure of the recharge to the zone of saturation.

Ground water is also discharged out of a basin by evapotranspiration, by withdrawal through wells and by subsurface underflow out of a basin. Evapotranspiration and withdrawal probably represent substantial quantities of discharge but direct measurement is not possible. Subsurface underflow out of the Big Creek basin could occur through the deposits that extend beyond the basin boundary but underflow out of the basin can be considered as equal to underflow into the basin.

Movement

The water level in a well is a measure of the fluid potential at a point. A well that encounters water that does not rise in the well is said to be under water-table conditions. Where the water does rise, the well is said to be under artesian conditions. Flow nets can be constructed to show the distribution of fluid potential by means of equipotential lines, and, because ground water moves from areas of higher to lower fluid potential, the direction of movement can be determined, as can hydraulic gradient.

Figure 33 is a contour map showing a generalized configuration of the water-table in the basin. Figure 34 is a contour map showing a generalized configuration of the piezometric surface of artesian aquifers in the basin. The figures were constructed from water-level data gathered over a number of years and therefore, may contain inherent errors; however, the data are deemed reasonably accurate to illustrate generalized conditions.

In many respects, the figures are similar. Both show that ground-water movement is towards Big Creek and its tributaries. In many areas, elevations on both surfaces coincide closely indicating lateral movement toward Big Creek. Drilling near Vanessa and Walsingham showed that the piezometric surface was lower than the water-table, indicating a downward component of flow. This is possibly true for much of the basin. Rates of movement were not determined but uniformity of contour spacing in many areas suggests that flow is fairly constant in southern areas. Broader spacing in northern parts suggests slower

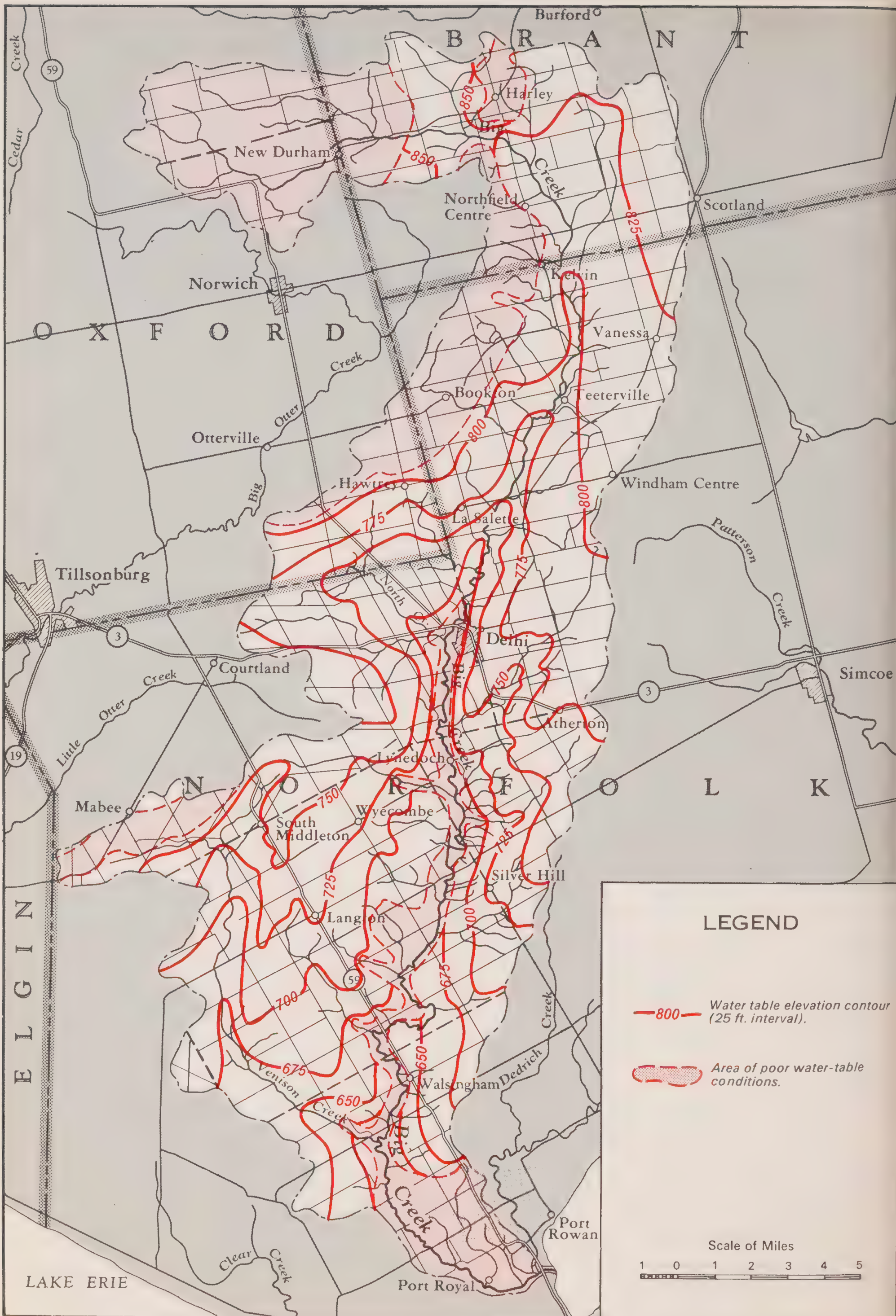
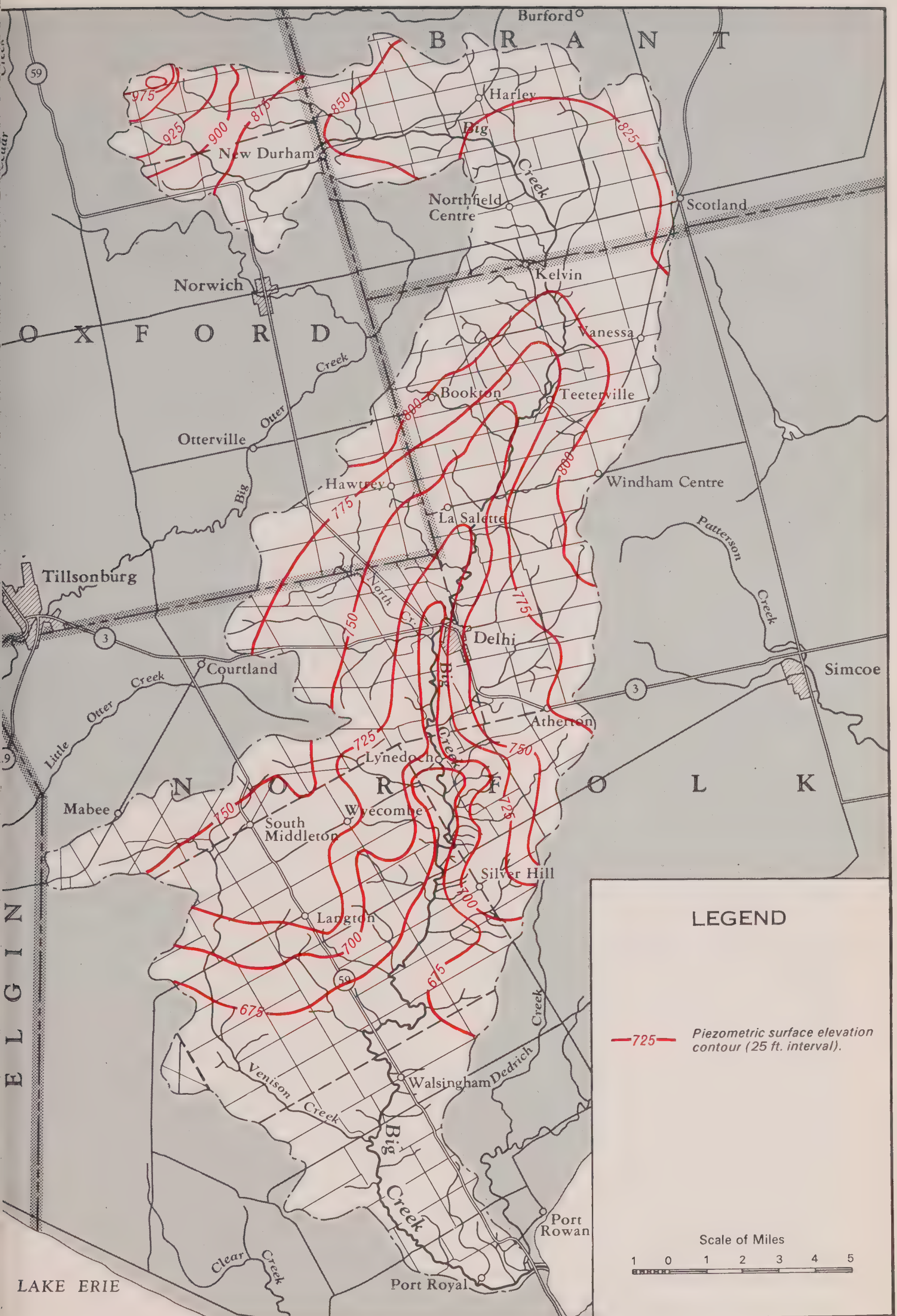


Figure 33. Generalized configuration of the water table, Big Creek basin.



igure 34. Generalized configuration of the piezometric surface, Big Creek basin.

rates of movement associated with the lower gradient conditions, although the permeability of the water-bearing formations may be somewhat higher in the north.

Recharge and Storage

Water in the zone of saturation represents ground water in storage. Based on an average, saturated, overburden thickness of 150 feet and an average porosity of 20%, the amount of ground water in storage in the overburden basin is equivalent to 30 feet of water over the entire basin or an average of 5.2 billion gallons of water per square mile. Although a large part of the water is in motion, only a part of it is recharged and discharged annually.

The amount of water that is actually recharged to the zone of saturation annually is relative to the amount of precipitation that enters the zone. Recharge rates vary seasonally because of climatic and hydrologic conditions and produce seasonal fluctuations in the water-table and, therefore, in the amount of water in storage. The fluctuations are brought about by differences in recharge and discharge rates to and from the zone. During the winter and spring, recharge exceeds discharge and water is taken into storage. During much of the remainder of the year, discharge generally exceeds recharge and water is released from storage.

To observe seasonal water-table fluctuations, ten water-table wells were selected in different geologic settings. The water-levels were measured manually on a weekly basis from July 1964 to June 1965. The locations of the wells are shown in Figure 35 and Map 2706-7. Hydrographs of the water-levels for six wells are shown in Figure 36. Technical difficulties prevented the use of the remaining observation wells.

The hydrographs show general rises in the water-table from December to April, and general declines from May to November. Abnormally high precipitation in August 1964 caused water-levels to rise above seasonal normals. Under normal conditions, most ground-water recharge probably occurs during the winter and spring seasons, during which time maximum ground water is taken into storage. During the recharge period, water-levels rises ranged from 2.25 to 7.5 feet and averaged four feet. Lower rises in the water-table generally occurred in wells that bottomed in sand, while the largest rises occurred in wells that probably bottomed in finer-grained lacustrine deposits. Assuming a porosity of 20 per cent, the four-foot rise in the water-table represents about ten inches of recharge over the basin. This is equivalent to 0.4 mgd per square mile and is similar to the 0.5 mgd per square mile obtained by others for similar conditions (Walton, 1965).

During the field survey, drilling was carried out near Walsingham and Vanessa and observation wells and piezometer nests were installed (Figure 35) to determine the direction of vertical flow components. Water-level flucutuations recorded at different depths during 1965 and 1966 are shown in Figure 37.

The Walsingham site is located on Conservation Authority property and consists of a seven-inch casing set at a depth of 47 feet with the bottom six feet slotted (Observation Well No. 138), and 1½-inch pipes set at 145 feet (Observation Well No. 139) and 307 feet (Observation Well No. 140). The Vanessa site is also located on Conservation Authority property and consists of a seven-inch casing set at 122 feet (Observation Well No. 136) and a 1¼-inch pipe set at 25 feet (Observation Well No. 137). Subsequently, wells No. 138 and 136 were equipped with automatic water-level recording devices. A program of manually measuring wells 139, 140 and 137 on a weekly basis was instituted. The efforts of the Big Creek Region Conservation Authority have been appreciated in this regard.

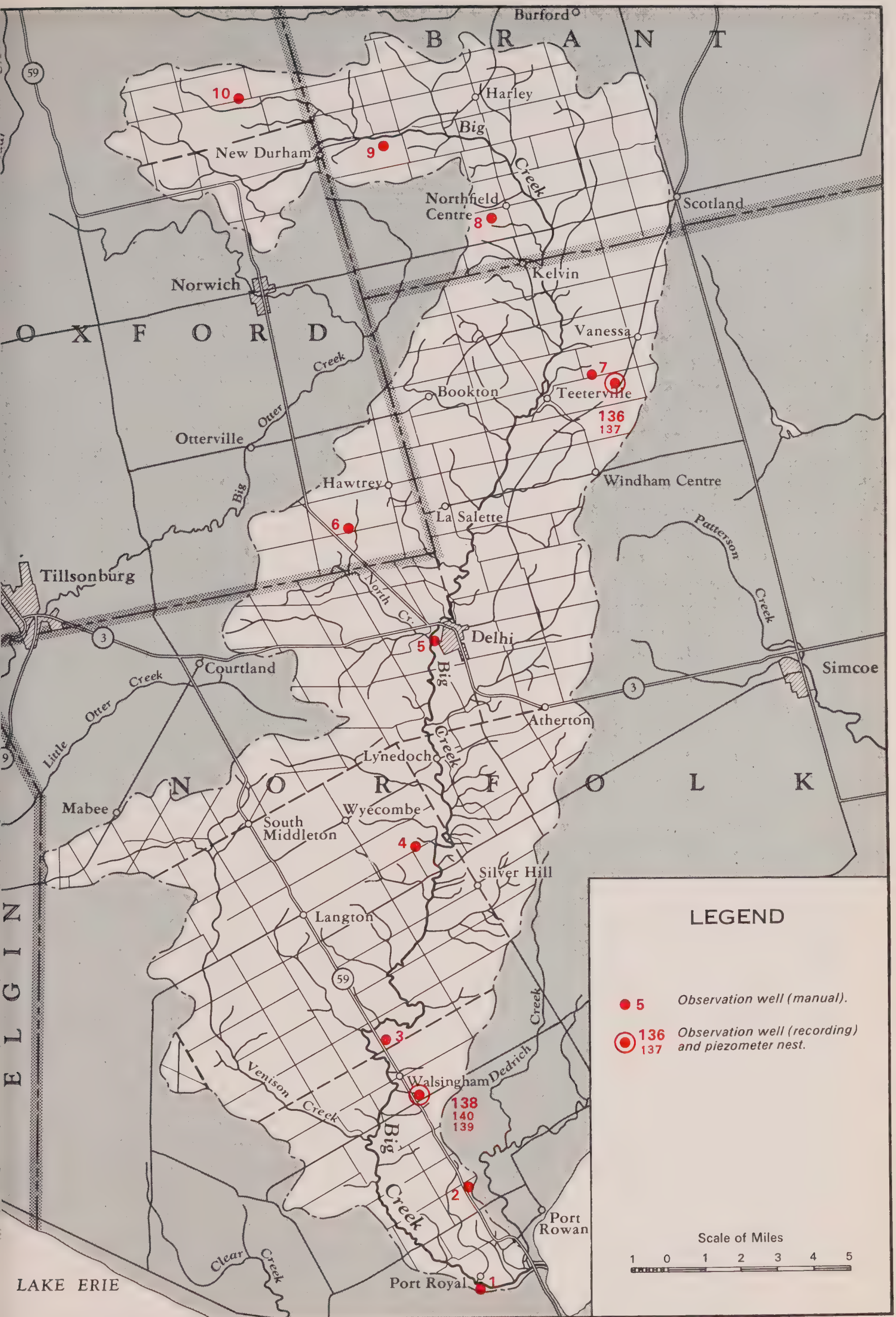


Figure 35. Location of observation wells and piezometers, Big Creek basin.

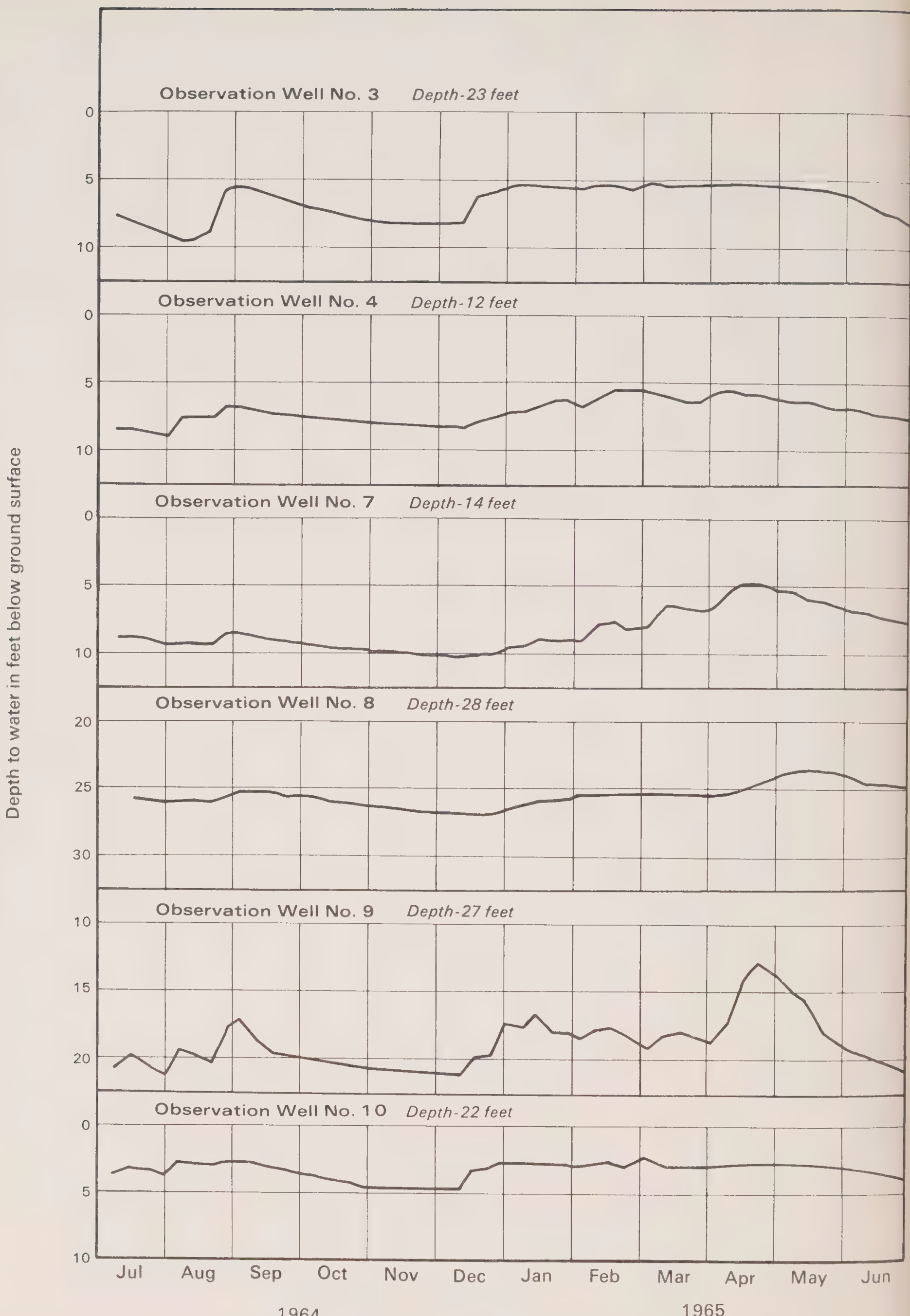


Figure 36. Hydrographs of water-level fluctuations in shallow wells, Big Creek basin.

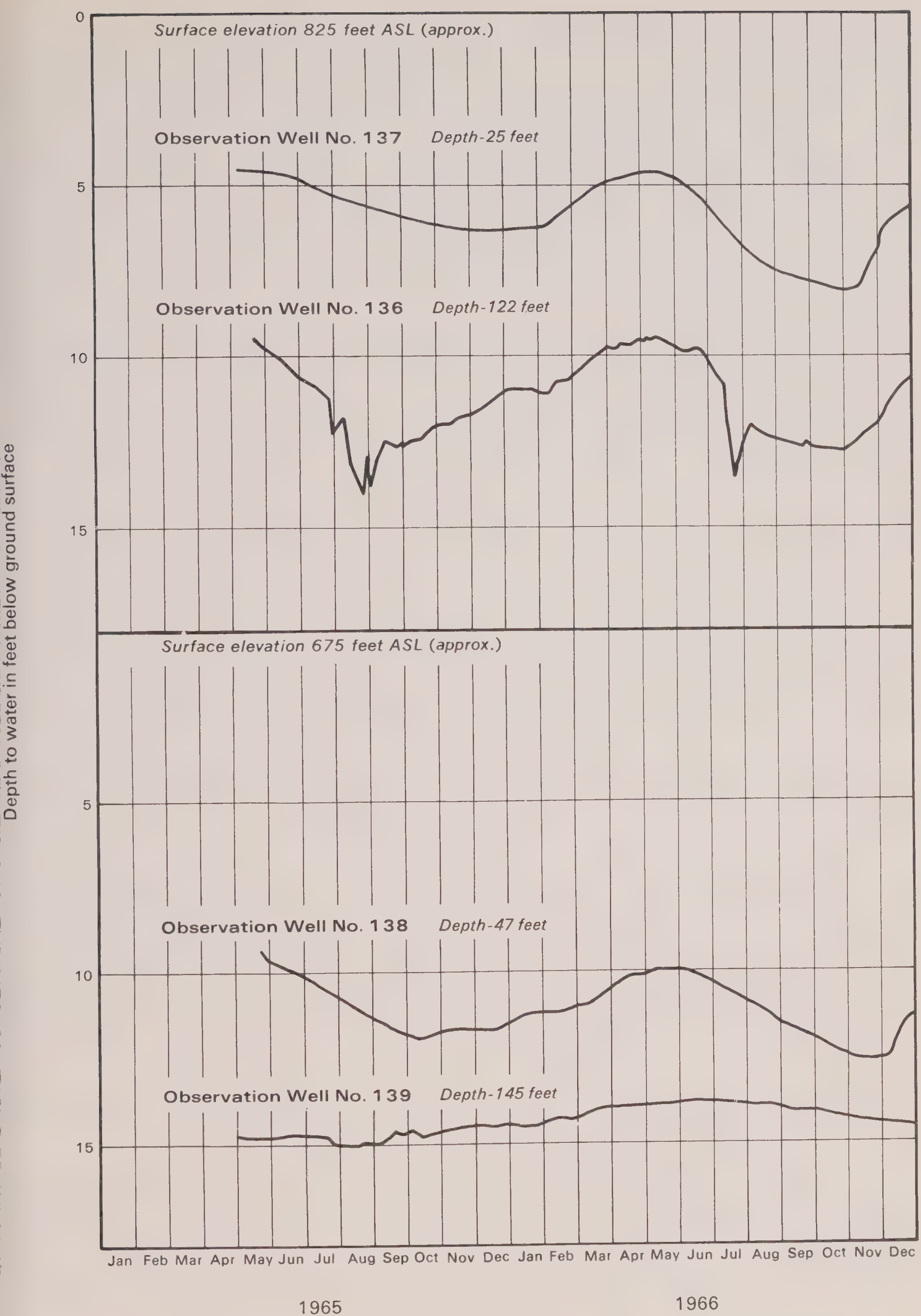


Figure 37. Hydrographs of water-level fluctuations in two observation well nests, Big Creek basin.

Recharge conditions prevailed at the Vanessa site through the observation period because of the downward gradient which averaged 0.50 feet per foot of depth between wells 136 and 137. The amplitude of fluctuation of these wells is similar to the other shallow observation wells. The effects of high-capacity irrigation wells in the area are apparent in the hydrograph for well 136.

The conditions prevailing at the Walsingham site were difficult to evaluate because of abnormal water-level fluctuations in the two small diameter piezometers. A downward gradient from a depth of 47 feet to 145 feet is, however, apparent, and suggests recharge conditions. The hydrograph for well 140 showed a continual decline throughout the period of observation and is unexplainable. The hydrograph for well 138 shows similar characteristics to other shallow well hydrographs.

The hydrographs generally show good hydraulic connection throughout the overburden even though interbedded clays and silts predominate.

The direct measurement of the total annual ground-water recharge is very difficult and complex. Work by others in this field shows that average annual recharge rates may vary from as low as 0.05 mgd per square mile (million gallons per day per square mile) for till areas to as high as 0.50 mgd per square mile for sand areas (Walton, 1965). These values can probably be considered representative of the contrasting conditions that occur in the basin. Expressed in inches of water, these values indicate amounts of natural ground-water replenishment ranging from 1.26 to 12.6 inches per year. In the Big Creek basin the latter value can be expected to prevail because sand covers a large portion of the basin. These values are indicative of the yearly potential for recharge but probably exceed the actual, annual ground-water discharge to streams. Because of the relatively shallow water-table conditions on the sand plain and in the numerous swampy areas, a substantial amount of water is probably lost to evapotranspiration. A certain portion is also lost to withdrawal.

A measure of the recharge can be obtained through the measurement of ground-water discharge as base flow to streams and is dealt with under discharge.

Ground-Water Discharge or Runoff

Ground-water discharge or runoff (R_g) is precipitation that infiltrates into the ground to the water-table and then percolates to streams as base flow. When streamflow consists entirely of ground-water runoff, a relationship exists between ground-water levels and streamflow. When plotted graphically, the full relationship is apparent. This form of analysis was used to determine ground-water runoff within the basin.

Rating curves were prepared to determine the relationship between the average ground-water level or stage and the ground-water discharge or runoff at the streamflow gauges near Delhi and Walsingham for the period of July 1964 to July 1965; the period for which data were available.

Fluctuations of the water-table in the basin were obtained from the hydrographs of selected wells shown in Figure 36. Mean daily ground-water stages were computed for selected dates when streamflow was considered to be entirely ground-water runoff at the gauging stations. For the Delhi gauge, the mean ground-water stage is an average of the depths to water below land surface at observation wells No. 4, 7, 8, 9, and 10. Well No. 4 is downstream of the gauge but was included to make the average more representative of conditions prevailing in a large part of the drainage area. For the Walsingham gauge, the mean ground-water stage is an average of the depths to water at observation wells No. 3, 4, 7, 8, 9 and 10.

Mean ground-water stages were plotted against ground-water runoff on corresponding dates and a line-of-best-fit was drawn through the points to produce rating curves for each gauging station. The rating curves are shown in Figure 38. Ground-water runoff or discharge corresponding to each mean ground-water stage was read directly from the rating curves and plotted on the yearly streamflow hydrographs shown in figures 21 and 22.

Work by others has shown that evapotranspiration will affect the relationship between ground-water stage and discharge. Data, however, were insufficient to establish the effect, although some points indicated deflections in the curves. The points selected occurred during low and moderately high evapotranspiration periods and the composite rating curves were, therefore, assumed to represent all conditions.

Monthly and annual ground-water runoff or discharge, per square mile expressed in gallons per day, cubic feet per second, and inches, were computed for each gauging station from the base-flow hydrographs shown in figures 21 and 22 and are given in Table 27. The relationship could not be established for the entire basin because of the lack of a gauging station at the mouth of the drainage basin, however, a prorated annual runoff value was calculated and is shown in the table.

The data show that ground-water discharge is highest during the spring and lowest during the summer and fall. Abnormally high precipitation in August 1964 resulted in abnormally high ground-water levels during August and accounts for the modest increase in ground-water runoff in August and September, but conditions were probably near normal by the end of the year because of below-normal precipitation in September and October.

Ground-water runoff amounted to 40 per cent and 48 per cent of streamflow in Big Creek during the selected annual period at the Delhi and Walsingham gauges, respectively. The reliability of the Walsingham gauge is probably somewhat less than the Delhi gauge and the runoff values may, in fact, be similar. On the other hand, hydrologic and topographic conditions below Delhi suggest that ground-water runoff in the southern part of the basin may be greater. The 60 square miles of drainage area below the Walsingham gauge has conditions similar to those above Walsingham and Delhi, and therefore, a runoff of 40 per cent is probably applicable to the entire basin. Precipitation during the selected yearly period was near normal, and therefore, the runoff is probably representative of near-normal conditions.

Base-flow or ground-water discharge-duration curves were prepared for the period of study and apear in figures 23 and 24. The curves show that 50 per cent of the time, ground-water discharge is equal to or greater than 56 cfs at the Delhi gauge and 101 cfs at the Walsingham gauge.

Evapotranspiration

Evapotranspiration, one of the main elements in the hydrologic cycle, represents the return flow of water to the atmosphere and is therefore an important meteorological process. At the surface of a body of water, whether large such as a lake, or small such as a puddle, there is an exchange of water-vapour molecules between the water surface and the atmosphere. When the net flux of water molecules results in a loss of water, evaporation occurs; and when it results in an increase of water, condensation occurs.

The physical process of evaporation is also responsible for the removal of water from plants and soils; however, the rate of water loss is affected strongly by the rate at which the soil and/or plant can move water to its evaporating

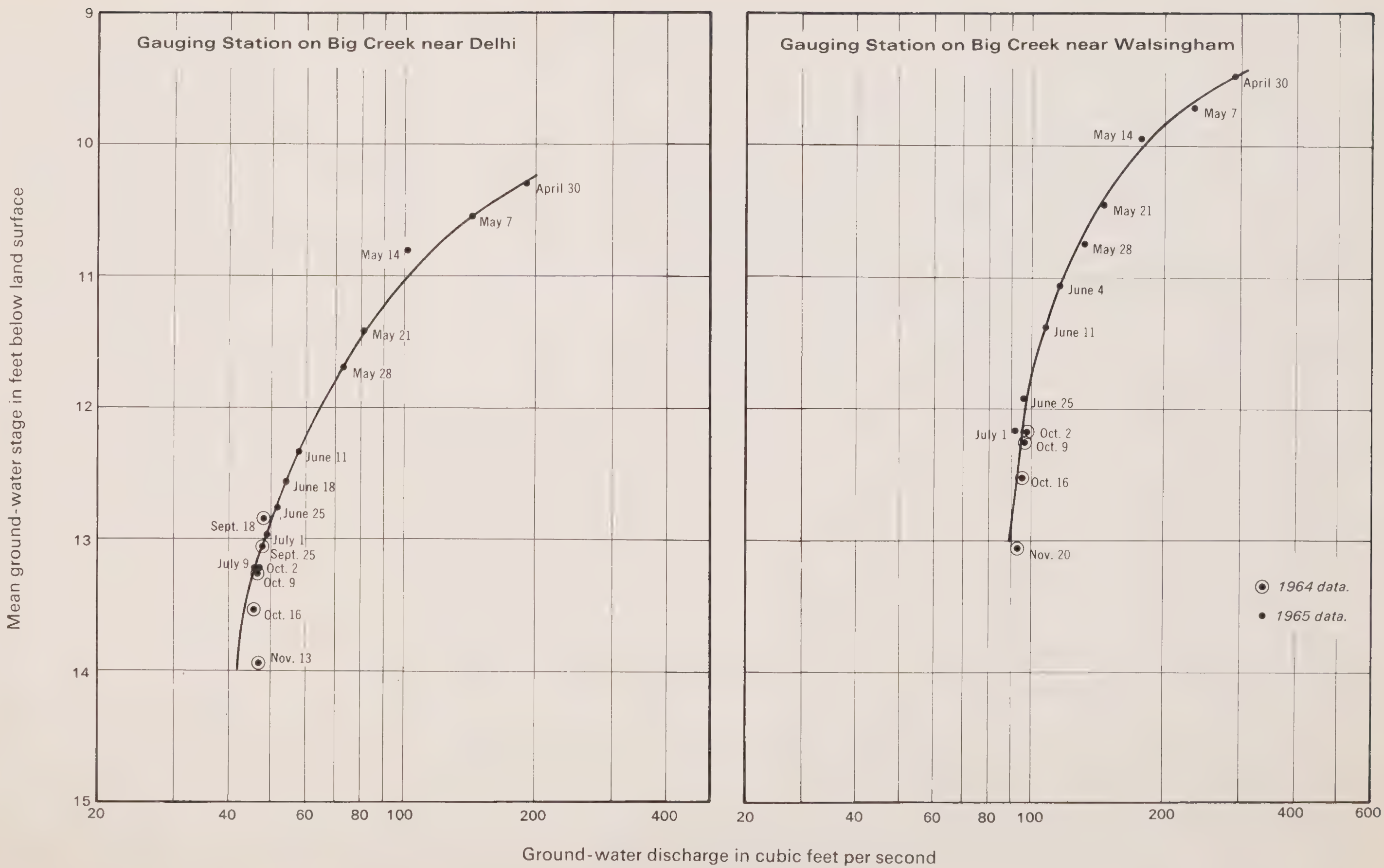


Figure 38. Rating curves of mean ground-water stage versus ground-water discharge, Big Creek basin.

Table 27. **Monthly and Annual Ground-Water Runoff, July, 1964 to June 1965 Big Creek Basin**

Drainage Area	Period	Precipitation (P)	Total Runoff (R)	Ground-Water Runoff per Square Mile (R_g)			
		Inches	Inches	Inches	MGD	CFS	As % of R
Above Gauging Station on Big Creek near Delhi. Drainage area = 142 sq. mi.	Jul 1964	3.71	0.40	0.37	0.17	0.32	92.5
	Aug	10.26	0.75	0.40	0.19	0.35	53.4
	Sep	0.73	0.48	0.42	0.20	0.38	87.5
	Oct	1.58	0.41	0.37	0.17	0.32	90.4
	Nov	0.90	0.40	0.37	0.18	0.33	92.5
	Dec	3.19	0.73	0.39	0.18	0.34	53.4
	Jan 1965	3.86	1.01	0.47	0.22	0.41	46.5
	Feb	3.10	2.47	0.47	0.23	0.43	19.0
	Mar	4.37	3.86	0.55	0.26	0.48	14.3
	Apr	2.91	3.43	1.03	0.50	0.92	30.0
	May	1.27	0.89	0.87	0.40	0.75	98.0
	Jun	1.54	0.46	0.45	0.22	0.40	98.0
	Annual	37.44	15.29	6.16	0.24	0.45	40.2
Above Gauging Station on Big Creek near Walsingham. Drainage area = 221 sq. mi.	Jul 1964	3.39	0.49	0.46	0.21	0.40	93.0
	Aug	10.39	1.04	0.48	0.22	0.42	46.1
	Sep	0.82	0.63	0.51	0.25	0.46	81.0
	Oct	1.60	0.50	0.49	0.23	0.42	98.0
	Nov	0.94	0.48	0.47	0.23	0.42	97.9
	Dec	3.33	0.86	0.50	0.23	0.43	58.1
	Jan 1965	3.86	1.07	0.57	0.27	0.49	53.2
	Feb	3.11	1.72	0.57	0.28	0.53	33.2
	Mar	4.66	4.11	0.69	0.32	0.60	16.7
	Apr	2.89	2.85	1.06	0.51	0.95	37.2
	May	1.30	0.96	0.93	0.44	0.81	96.8
	Jun	1.54	0.53	0.52	0.25	0.46	98.1
	Annual	37.83	15.24	7.25	0.29	0.53	48.0
Total Drainage Basin. Drainage area = 280 sq. mi.	Estimated Annual	38.2	15.2	7.0	0.28	0.52	46.0

surfaces. The term “evapotranspiration” is used to describe water loss to the atmosphere from the combined water, soil, and plant evaporating surfaces; and the term “potential evapotranspiration” is used to describe the rate of loss when the supply of water in the soil and plants is not limiting the rate of evapotranspiration. The rate of evapotranspiration depends mainly on solar radiation, air temperature, vapour-pressure differences between the atmosphere and the evaporating surfaces, wind velocity, soil-moisture supply, soil characteristics, and plant cover; or in more general terms, on three basic items: climate, soil-moisture supply, and plant cover.

It is practically impossible to measure evapotranspiration directly, and impossible to measure the evapotranspiration of a river basin; however, it can be estimated by using empirical formulas or, indirectly, by solving the hydrologic budget equation.

Theoretical Methods

A number of empirical formulas have been developed to estimate potential evapotranspiration under various field and meteorological conditions (Viehmeyer, 1964). Two of these, the ones developed by Thornthwaite and Penman were used in this study to determine monthly potential evapotranspiration values which are hopefully representative of the Big Creek basin. These values were calculated with the aid of the POTEV computer program (Freeze, 1967), using as input data those collected at the Delhi meteorological station for the Thornthwaite estimates and also data from the Simcoe station when not available for the Delhi site for the Penman estimates. The meteorological data are listed in the "Monthly Record," a monthly publication by the Meteorological Branch, Canada Department of Transport.

Table 28 shows the calculated monthly and annual potential evapotranspiration estimates for the 1963-1965 period as determined by the Thornthwaite method and the mean monthly temperatures used in these calculations.

Table 28. Mean Monthly Temperature and Estimated Monthly and Annual Potential Evapotranspiration at Delhi, Big Creek Basin, 1963-1965

(Potential evapotranspiration calculated by the Thornthwaite method)

Month	1963		1964		1965	
	Potential Evapo-transpiration (inches)	Mean Monthly Temperature (°F)	Potential Evapo-transpiration (inches)	Mean Monthly Temperature (°F)	Potential Evapo-transpiration (inches)	Mean Monthly Temperature (°F)
Jan	0.0	14.5	0.0	25.8	0.0	21.2
Feb	0.0	15.2	0.0	23.3	0.0	23.2
Mar	0.07	32.9	0.01	32.1	0.0	27.3
Apr	1.34	44.1	1.29	44.0	0.72	38.8
May	2.66	52.4	3.44	58.1	3.65	59.2
Jun	4.47	64.4	4.54	65.1	4.45	64.2
Jul	5.23	69.1	6.62	71.8	4.59	64.9
Aug	4.14	64.0	4.03	63.5	4.46	66.2
Sep	2.63	56.1	3.13	60.5	3.41	62.5
Oct	2.27	54.8	1.37	46.7	1.53	47.8
Nov	0.88	43.1	0.69	41.2	0.54	39.0
Dec	0.0	20.2	0.0	27.9	0.0	32.0
Year	23.69		24.12		23.35	

The monthly potential evapotranspiration values as determined by the Penman method did not appear to be suitable. The annual potential evapotranspiration values by this method for the years 1963, 1964 and 1965 are, respectively, 19.43, 19.70 and 19.30 inches. These values are about 82 per cent of the Thornthwaite estimates and appear less realistic. The Penman method is generally considered to be superior to the Thornthwaite method. It requires considerably more meteorological data which are not available normally at most meteorological stations. The empirical input values required for the Penman estimates have not yet been adequately defined by experimentation for southern Ontario conditions.

Indirect Method

The actual evapotranspiration values can be estimated indirectly by solving the hydrologic budget equation, but assumptions generally have to be made about changes in ground-water, soil-moisture and surface-water storage.

To arrive at a reasonable estimate of annual evaporation in the Big Creek basin the streamflow records at Big Creek near Delhi were investigated to select a period of years during which it could be assumed that no net change in ground-water and surface-water storage occurred between the first and last day of the record. The period October 1, 1962, to September 30, 1967, was selected from the total period of record as the total flow and the base flow at the starting and finishing dates were very similar. Furthermore, it was assumed that the net change in soil-moisture storage was negligible. The annual precipitation and runoff of the Big Creek basin above the Delhi gauge were determined for each of the five water years. The table below lists these values and the annual difference between precipitation and runoff.

Water Year October to September	Mean Daily Streamflow at Big Creek near Delhi on October 1 (cfs)		Annual Basin Precipitation P (inches)	Annual Basin Runoff R (inches)	Annual Difference P – R (inches)
	Total Flow	Estimated Base Flow			
1962-1963	63.2	54	28.04	8.79	19.25
1963-1964	34.0	32	33.27	6.81	26.46
1964-1965	50.2	48	33.45	14.67	18.78
1965-1966	62.3	40	35.44	9.82	25.62
1966-1967	51.0	48	36.88	12.01	24.87
1967	63.4	54			
Mean			33.42	10.42	23.00

The mean of 23.0 inches for the annual P—R values for this five-year period is considered to be a good estimate of the mean annual evapotranspiration because of the conditions set in selecting the period.

Summary

For comparison purposes the theoretical potential evapotranspiration as calculated for the Delhi meteorological station and the estimated actual evapo-

transpiration values for the Big Creek basin above the Delhi streamflow gauging station are presented below for the period October 1, 1962, to October 1, 1967:

Water Year	Potential Evapotranspiration at Delhi after Thornthwaite (inches)	Annual Difference (P — R) (inches)	Evapotranspiration (inches)
1962-1963	22.78	19.25	
1963-1964	25.21	26.46	
1964-1965	23.34	18.78	
1965-1966	23.61	25.62	
1966-1967	23.17	24.87	
Five-Year Mean	23.62	23.00	23.00

The Thornthwaite potential evapotranspiration value for the five-year mean is only 2.6 per cent larger than the estimated actual evapotranspiration as determined from the indirect method. This difference appears too small. The Thornthwaite annual value is only an estimate of potential evapotranspiration. Thornthwaite states (1948) that his potential evapotranspiration values are of the right order of magnitude from tests conducted throughout most of the United States, but that they are nevertheless only approximate. It appears that in the Big Creek basin his formula holds in a similar manner. Furthermore, the evapotranspiration during the winter months cannot be determined by the Thornthwaite method as it fails for temperatures below 32°F. During these months, evaporation and sublimation do occur; however, these water losses to the atmosphere are considered to be relatively small when compared to the other months of the year.

The irrigation practices in the basin increase the actual evapotranspiration rates during the summer period, but only slightly if one considers the basin as a whole. For instance, during the 1964 summer season the irrigation water applied on the tobacco crop in the basin was equivalent to 0.13 inches of water when spread over the Big Creek sub-basin above the Delhi streamflow gauging station. In other years this value may double due to climatic and economic factors; however, the additional water lost to the basin due to irrigation is relatively small.

It can be concluded from the assessment of the evapotranspiration in the basin that the potential evapotranspiration is about 24 inches per year and the actual evapotranspiration is about 23 inches per year.

Hydrologic Budget

A hydrologic budget is a quantitative statement of the balance between the amount of water entering and leaving a drainage basin over a specified period of time. Stated as an equation, the hydrologic budget can be defined as:

$$P = R_s + R_g + ET \pm U \pm S_s \pm S_{sm} \pm S_g$$

where
P = precipitation
R_s = surface or direct runoff
R_g = ground water or indirect runoff
ET = evapotranspiration
U = subsurface underflow, into and out of the basin
S_s = change in surface-water storage (includes snow and ice)
S_{sm} = change in soil-moisture storage
S_g = change in ground-water storage
$R_s + R_g$ = R = total streamflow or runoff

In a hydrologic budget for an annual or multi-annual period, net changes in S_s, S_{sm}, and S_g are often small in relation to the magnitude of the other terms. For the annual period selected for the preparation of the hydrologic budget in this report these terms were considered to be negligible and were disregarded.

By eliminating these terms, the budget equation can be reduced to a simpler form:

$$P = R_s + R_g + ET \pm U$$

Hydrogeologic evidence indicated that subsurface underflow in the basin was also probably negligible and this item was also disregarded in the equation.

The following simplified form of the hydrologic equation was thus used in the preparation of a budget for the Big Creek basin:

$$P = R_s + R_g + ET = R + ET$$

The main factors of the hydrologic budget are: precipitation, streamflow and evapotranspiration. The relationship between the above terms in the Big Creek basin is demonstrated in a hydrologic budget prepared for a one-year period, July 1, 1964, to June 30, 1965, for which the most complete data were available. The comparative results on a monthly and annual basis are listed in Table 29. The selection of values for the various parameters are discussed below.

Precipitation

Precipitation, including dew, rain and snow, is considered the only source of water entering the basin. The monthly precipitation values shown in Table 29 are those extracted from Table 7, network 2, for the period July to November 1964, and from Table 6 for the period December 1964 to June 1965. The annual values for the incremental area between Delhi and Walsingham and the total basin were derived from the same precipitation-gauge network as the values shown in tables 6 and 7.

The total precipitation for the July 1964 to June 1965 period as recorded at the Delhi meteorological station was 37.66 inches, which is identical to the annual normal computed from the period 1934 to 1960 and is slightly higher than the 1935 to 1967 mean of 37.02 inches. This indicates near normal conditions in comparison to average annual values. The precipitation distribution throughout the inventory period was, however, far from normal with extremely high precipitation in August and extremely low precipitation during September, October and November.

Table 29. Monthly and Annual Hydrologic Budget for Selected Drainage Areas, Big Creek Basin, July 1, 1964, to June 30, 1965

(All values expressed in inches of water. Runoff values for June, July, August and annual period adjusted for water withdrawal.)

Drainage Area	Period	Precipitation P	Runoff				Precipitation Minus Runoff	
			Total R	Direct R_s	Ground Water R_g	Rg as % of R	Monthly P–R	Annual P–R=ET
Above Delhi Gauging Station	Jul 1964	3.53	0.40	0.03	0.37	92.5	3.13	
	Aug	9.85	0.75	0.35	0.40	53.4	9.10	
	Sep	0.75	0.48	0.07	0.42	87.5	0.27	
	Oct	1.57	0.41	0.04	0.37	90.4	1.16	
	Nov	0.95	0.40	0.04	0.37	92.5	0.55	
	Dec	3.19	0.73	0.33	0.39	53.4	2.46	
	Jan 1965	3.86	1.01	0.53	0.47	46.5	2.85	
	Feb	3.10	2.47	2.00	0.47	19.0	0.63	
	Mar	4.39	3.86	3.31	0.55	14.3	0.53	
	Apr	2.91	3.43	2.40	1.03	30.0	0.52	
	May	1.27	0.89	0.02	0.87	98.0	0.38	
	Jun	1.54	0.46	0.01	0.45	98.0	1.08	
	Annual	36.91	15.29	9.13	6.16	40.2		21.62
Above Walsingham Gauging Station	Jul 1964	3.37	0.49	0.03	0.46	93.0	2.88	
	Aug	10.03	1.04	0.56	0.48	46.1	8.99	
	Sep	0.83	0.63	0.12	0.51	81.0	0.20	
	Oct	1.64	0.50	0.01	0.49	98.0	1.14	
	Nov	0.93	0.48	0.01	0.47	97.9	0.45	
	Dec	3.33	0.86	0.36	0.50	58.1	2.47	
	Jan 1965	3.86	1.07	0.50	0.57	53.2	2.79	
	Feb	3.11	1.72	1.15	0.57	33.2	1.39	
	Mar	4.66	4.11	3.42	0.69	16.7	0.55	
	Apr	2.89	2.85	1.79	1.06	37.2	0.04	
	May	1.30	0.96	0.03	0.93	96.8	0.34	
	Jun	1.54	0.53	0.01	0.52	98.1	1.01	
	Annual	37.49	15.24	7.99	7.25	48.0	22.25	22.25
Between Walsingham and Delhi Gauging Stations	Annual	38.57	15.15	5.94	9.21	61.0	23.42	23.42
Total Basin	Estimated Annual	37.9	15.2	8.2	7.0	46	22.7	22.7

Runoff

Total runoff values used are those determined from streamflows recorded at the Delhi and Walsingham gauging stations on Big Creek and plotted on figures 21 and 22. Total streamflow was divided into its two main components, direct or surface runoff and indirect or ground-water runoff or base flow.

Withdrawals of water from streams and from ground-water sources affect the daily streamflow values during the summer months. During July 1964 the effects were 0.06 and 0.09 inches for the sub-basins terminating at Delhi and at Walsingham respectively. These reductions are equivalent to 15 and 18 per cent of the monthly runoff at these gauging stations. To achieve a budget of near natural conditions, recorded streamflows were adjusted upward to compensate for water withdrawals.

The adjustments were made on a daily basis and were based on changes in ground-water stages at selected observation wells using ground-water stage-ground-water discharge relationships (Figure 38) developed for the sub-basins terminating above Delhi and above Walsingham.

The total runoff at the Delhi and Walsingham gauges, as calculated for the selected period, was 15.29 and 15.24 inches, respectively, or 41.4 and 40.6 per cent of the estimated sub-basin precipitation. Base flow or ground-water runoff constituted about 40 and 48 per cent of the total streamflow at the respective gauges. The increased value indicates a larger proportion of ground-water discharge in the drainage area between the gauges. The estimated ground-water discharge for the portion of the basin between these gauges is about 61 per cent of the total runoff originating in this sub-basin.

The estimated total runoff from the entire Big Creek basin was 15.2 inches, of which about 46 per cent was probably ground-water discharge.

Evapotranspiration

For budget purposes, evapotranspiration was calculated by two methods: the Thornthwaite method for potential evapotranspiration, and the indirect method for actual evapotranspiration. The latter method consisted of solving the simplified hydrologic equation $ET = P—R$.

From data at the Delhi meteorological station, the potential evapotranspiration by the Thornthwaite method was estimated to be 23.66 inches. This value may be taken to be representative of the potential evapotranspiration in the Big Creek basin. By the indirect method, the estimated actual evapotranspiration for the budget period for the sub-basins above the Delhi and Walsingham streamflow gauges was 21.62 and 22.25 inches, respectively. These values are about six and four per cent smaller than the potential evapotranspiration estimate.

These values agree well with the average evapotranspiration of 23.00 inches calculated by the indirect method for the five-year period October 1962 to September 1967.

WATER QUALITY

Water quality can be as important a factor to proper water management and development as quantity. Although abundant quantities may be present, use of the water may be restricted because of quality considerations. Quality requirements vary with purpose and may affect the use of the water or make treatment necessary.

The purpose of this section is to discuss the chemical quality aspects of surface and ground waters in the basin in terms of their chemical constituents and characteristics and their suitability for selected purposes. The suitability of waters for domestic and irrigational purposes are discussed in detail because of the demand for water for these purposes. A secondary purpose of the water sampling and analysis program was to attempt a hydrologic correlation between surface water and ground water based on chemical characteristics.

Water samples were taken from streams and wells in the basin during the period July 1964 to March 1965. One hundred and fifty-four samples were taken and analyzed; 101 from ground-water sources and 53 from surface-water sources. In all, 80 wells were sampled of which 67 were considered representative of quality conditions at different locations in the basin. Fourteen wells were sampled for hydrologic correlation purposes with surface water. Surface-water samples were collected from 18 different locations in the basin; 12 from Big Creek and 6 from tributaries. Samples were taken mostly at low-flow periods, especially those for hydrologic correlation purposes. The locations of the sampling points and related data are shown on Figure 39.

The results of the chemical analyses are tabulated in Appendix B. All analyses were done at the laboratories of the OWRC where an accuracy of 5% for the main anions and cations is an objective standard. All values in the table, except pH and specific conductance, are reported as "parts per million" (ppm); however, actual determinations were on a milligram per litre basis. The specific conductance values are reported as micro-mhos per cubic centimeter at 25°C. Compilation and comparison of constituent concentrations in graphical form are difficult in terms of ppm, and "equivalents per million" (epm) were used to facilitate the comparison. The following factors were used to convert ppm values listed in Appendix B to epm values in terms of the ion shown in brackets:

Calcium	(Ca)	- 0.04990	Bicarbonate	(HCO_3)	- 0.01639
Magnesium	(Mg)	- 0.08224	Carbonate	(CO_3)	- 0.03333
Sodium	(Na)	- 0.04350	Chloride	(Cl)	- 0.02820
Iron	(Fe)	- 0.03581	Nitrate	(NO_3)	- 0.01613
Potassium	(K)	- 0.02558	Sulphate	(SO_4)	- 0.02082

All of the samples collected from 98 different locations were used in the discussion of constituents. In the diagrams, however, only 50 samples (one per source) were used in the detailed presentation of water quality. The 50 samples were considered representative of most conditions in the basin and included 21 from overburden, ground-water sources, 11 from bedrock, ground-water sources and 18 from stream, surface-water sources (Figure 39). The analyses for all samples are listed in Appendix B.

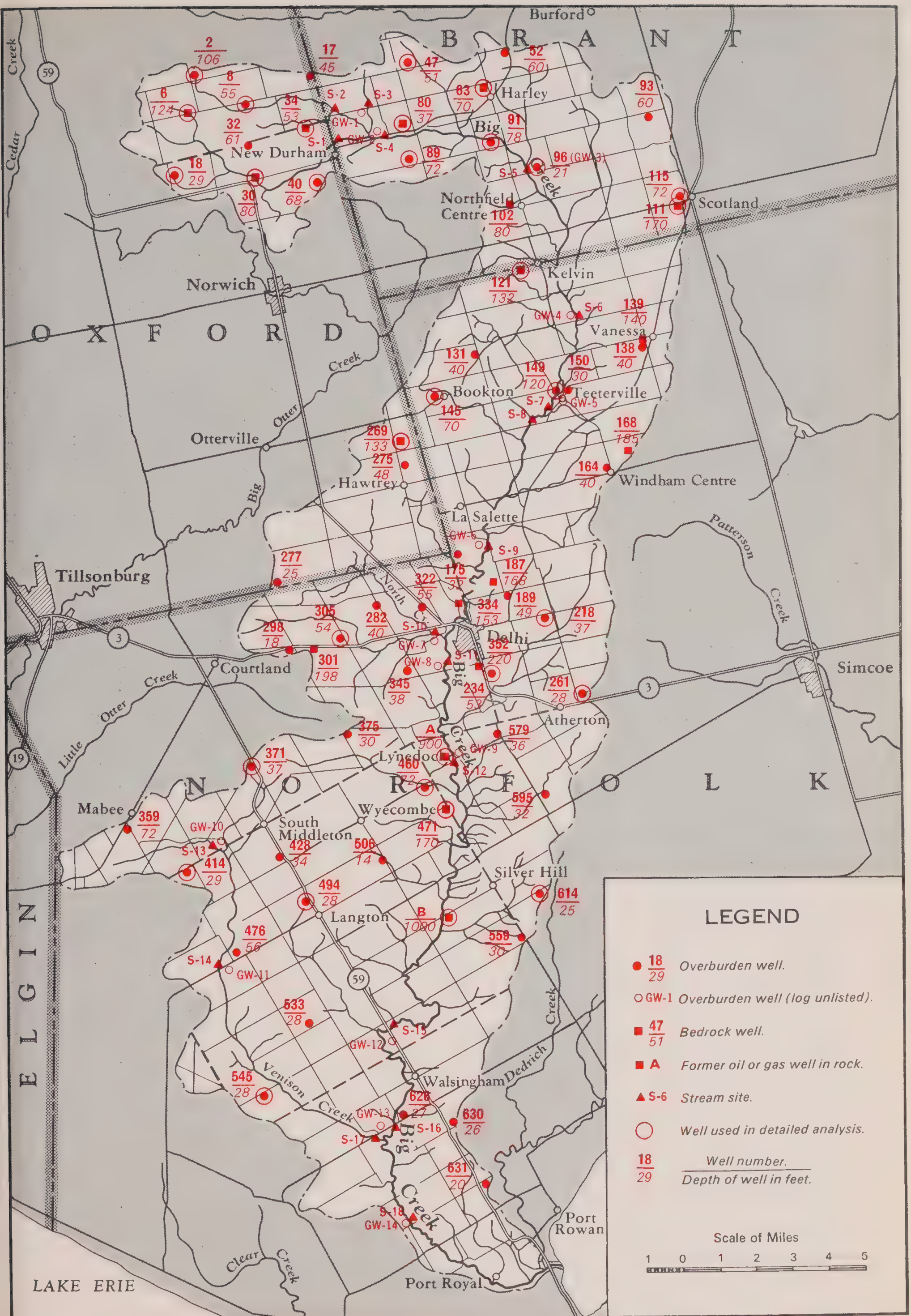


Figure 39. Location of surface-water and ground-water sampling points, Big Creek basin, 1964.

Chemical Constituents and Characteristics

The processes by which natural waters acquire their chemical characteristics are complicated, but by studying the results obtained from water analyses an insight can be gained into the chemical reactions involved and the environment conditions prevailing in an area.

In the following paragraphs the major constituents present in the analyzed water samples are discussed in some detail to provide an understanding of the nature of each constituent, possible sources from which it may have been derived, its chemical significance and the range of concentrations present in waters in the basin. Different methods of correlation are used to show the associations between significant constituents and properties.

Included in the major constituents are the cations of calcium, magnesium, sodium and potassium and the anions of bicarbonate, sulphate, chloride and nitrate. Although considered, carbonates were neglected because of their absence. Lesser constituents are iron, hydrogen sulphide and silica. More general chemical properties discussed include hydrogen-ion concentration (pH), hardness, alkalinity, total dissolved solids and specific conductance. The concentrations of the major cations and anions and chemical properties of 50 water samples are presented in various figures to assist in the understanding of water-quality conditions throughout the basin.

Calcium

Calcium is an alkaline-earth metal that has widespread occurrence in rocks and soils and, because of its ready solubility, is present in nearly all waters. Its presence in water is significant because it contributes to the hardness of water when abundant bicarbonate ions are present. Calcium is present in a number of silicate and non-silicate-type rocks but, because the latter are generally more soluble, waters in the latter generally have higher concentrations of calcium. This is reflected in the water in non-silicate-type rocks, which is usually much harder.

In the Big Creek basin calcium concentrations range from 19 to 168 ppm, with a median concentration of 66 ppm in water samples taken from wells that obtain water from the overburden or the upper part of the bedrock. Deeper penetration into bedrock usually results in higher concentrations, the maximum obtained being 488 ppm in Well A, a former gas and oil test well believed to be about 900 feet deep.

In surface-water samples the calcium concentration ranges from 64 to 120 ppm with a median concentration of 80 ppm. The similarity to ground water is apparent and indicates the dependency of streamflow on ground-water discharge at the time of sampling.

Calcium constitutes about 50 to 80% of the cation concentration. The calcium concentrations are typical of an environment in which there is an abundance of non-silicate-type minerals present. The water-bearing sand and bedrock formations are mainly carbonate in nature and are the primary source of the calcium. At depth in the bedrock certain soluble sulphate minerals are present and are an added source of calcium.

Magnesium

Magnesium belongs to the same group of alkaline-earth metals as calcium and is comparable to calcium in occurrence in rocks, solubility and presence in most waters. It also contributes to the hardness of water.

Magnesium concentrations in ground-water samples from the Big Creek basin range from 2 to 100 ppm, but the median concentration is 18 ppm. In surface-water samples the concentrations range from 8 to 31 ppm and probably reflect the base-flow conditions in the streams at the time of sampling.

Magnesium constitutes about 20 to 40% of the cation concentration and reflects similar environmental conditions as calcium.

Calcium-Magnesium Ratio

In many natural waters calcium is usually more abundant than magnesium and the ratio of calcium-to-magnesium, in equivalents per million, is an indication of the irrelative abundance in the soils and waters in the area. The ratio for natural waters commonly ranges from about 5.0 to 1.0. The ratio for bedrock wells in the basin ranges between 4.3 to 0.9 but is generally less than 3.0 in the northern part of the basin and more than 3.0 in the southern part. The ratios for overburden wells display similar characteristics. Ratios for surface-water samples are not as definitive but may suggest similar conditions. The lower values of the ratios suggest that magnesium is more abundant in soils and rocks in the northern part of the basin. The calcium-magnesium ratios in surface and ground water throughout the Big Creek basin are shown in Figure 40.

Sodium

Sodium is an alkali metal and, although a common constituent in silicate rocks, is ordinarily scarce in carbonate rocks but abundant in evaporite sediments. Most sodium compounds are readily soluble and sodium is often present in all waters to some degree. Its common occurrence as sodium chloride and its solubility in water can readily impart a salty taste to water. Waters with high concentrations of sodium are believed to be hazardous to human health and plants. The hazard of sodium to plants is discussed in greater detail in later paragraphs.

Sodium concentrations range from 3 to 39 ppm but are usually less than 20 ppm in ground-water samples from wells in the overburden and the upper part of the bedrock in the Big Creek basin. Surface-water samples display similar concentrations. Information is available for only two wells deep in the bedrock and these show concentrations of 153 and 353 ppm. Evaporite beds are known to occur at depth in the bedrock and are the likely source of high sodium concentrations. Sodium generally constitutes less than 20% of the cation concentrations. The sodium concentrations in waters in the basin are shown in Figure 41.

Potassium

Potassium is an alkali metal like sodium and has many similar traits to it. Its occurrence is also similar to sodium but because it tends to be less soluble its presence in natural waters is usually much lower. Because of its similarities to sodium it is commonly considered in conjunction with sodium.

Potassium concentrations vary up to 22 ppm in ground-water samples for the Big Creek basin but are generally less than 5 ppm in most instances. Sufficient analyses were not carried out to establish any pattern to the occurrence

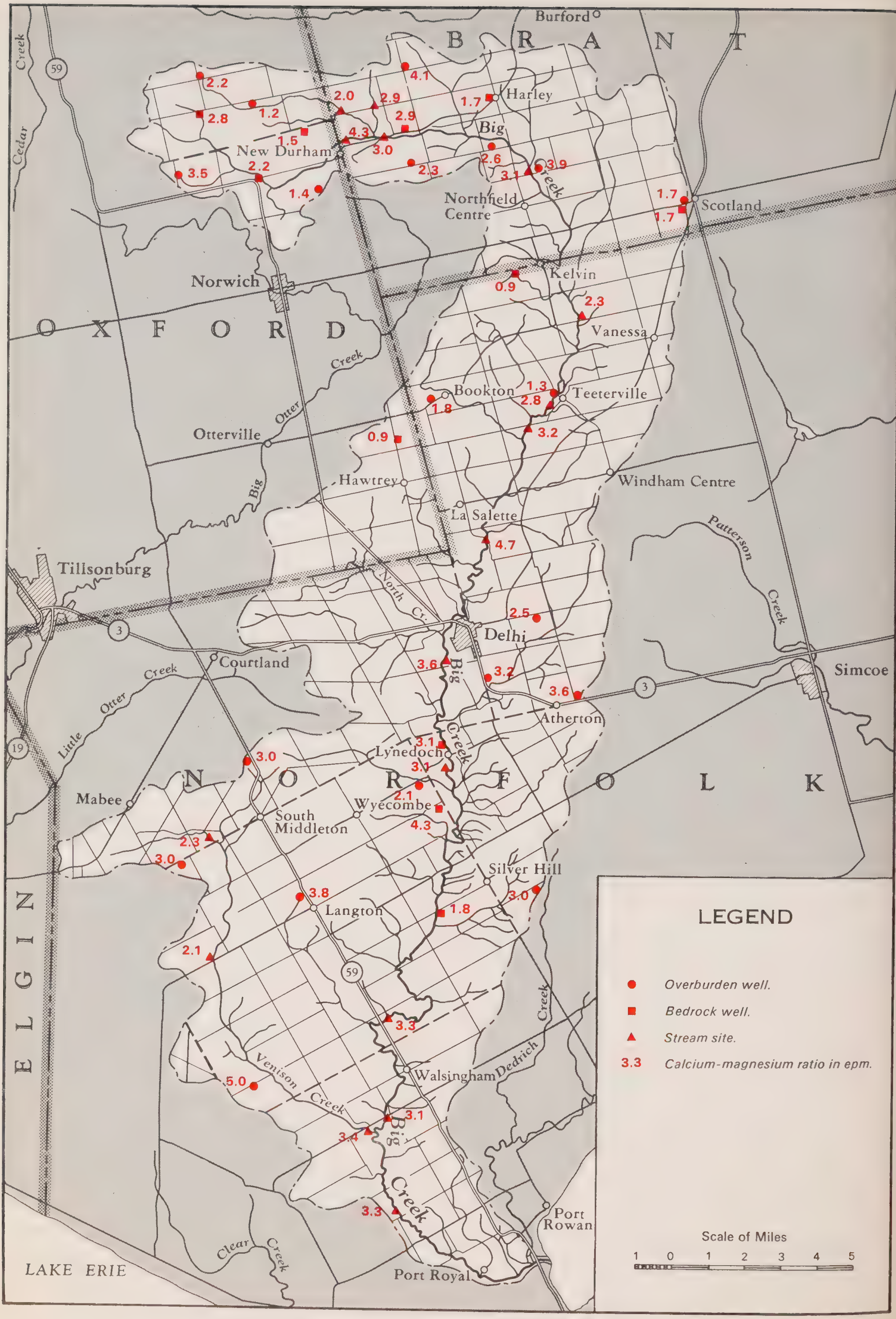


Figure 40. Calcium-magnesium ratio in surface water and ground water, Big Creek basin, 1964.

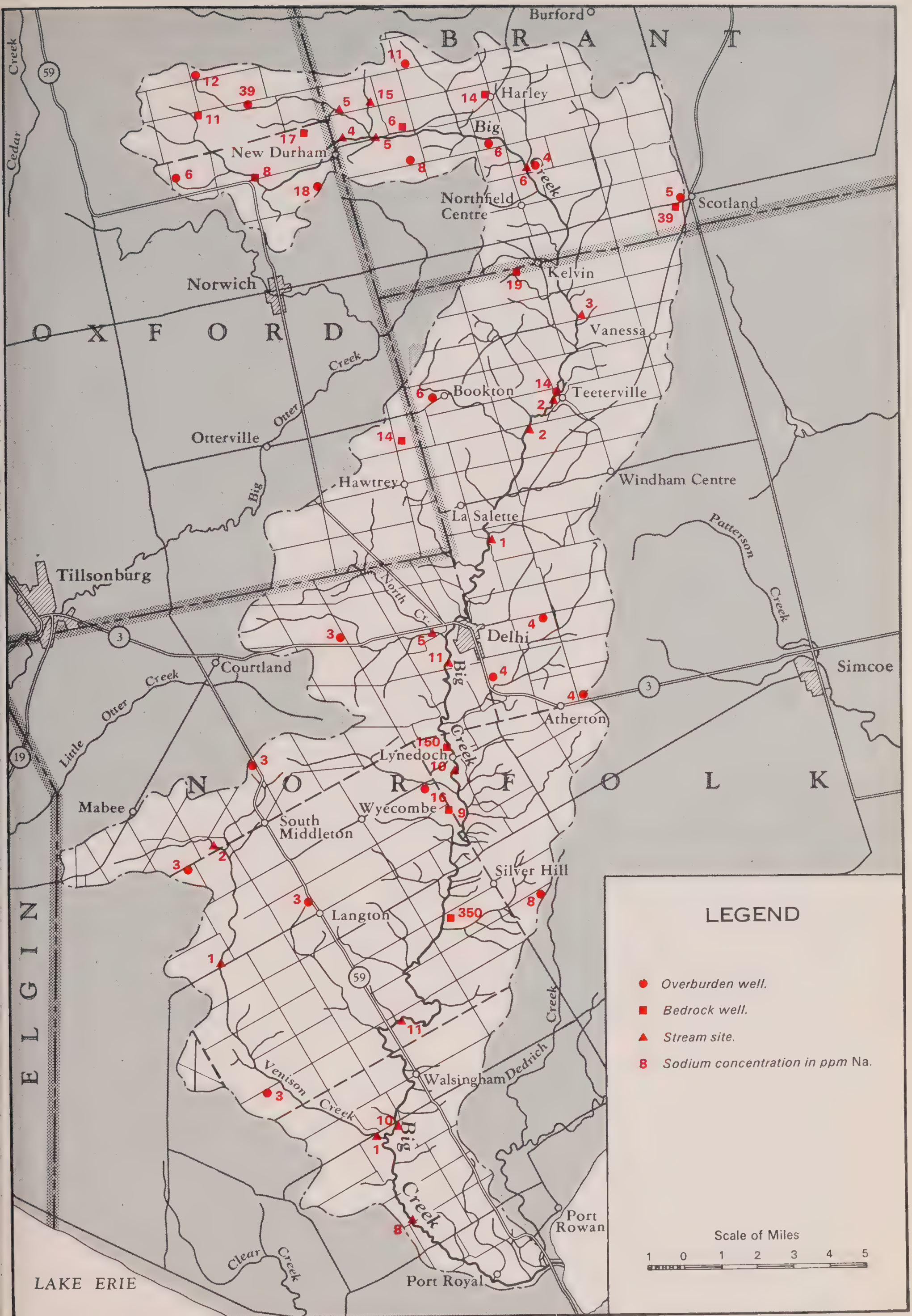


Figure 41. Sodium concentration in surface water and ground water, Big Creek basin, 1964.

of potassium. Surface-water samples also generally contain concentrations less than 5 ppm. Potassium generally constitutes less than 1% of the cation concentration.

Alkalinity — Bicarbonate and Carbonate

Alkalinity in water is the ability to neutralize acid and is a measure of the anions of bicarbonate, carbonate, or hydroxide present in solution, with the type of anion or anions present in a solution dependent on the pH of the water. Because of the relative abundance of carbonate minerals in most soils and rocks, bicarbonate and carbonate can be expected in many waters. Hydroxide, when present, may indicate unnatural concentrations. Because of the pH of the waters in the Big Creek basin, the alkalinity is entirely bicarbonate.

The alkalinity in ground-water samples generally ranges from 104 to 360 ppm, expressed as $CaCO_3$, and 137 to 440 ppm expressed as HCO_3. Surface waters display similar ranges of alkalinity. The bicarbonate alkalinity in the waters in the basin reflects the abundance of carbonate materials present in the basin (Figure 42). Bicarbonate constitutes 60 to 95% of the anions present in the natural waters.

Sulphate

Sulphate is oxidized sulphur. Most sulphates are readily soluble in water and are common in low concentrations in most waters. They may be derived from the oxidation of sulphides of heavy minerals or the dissolving of sulphate-bearing evaporites such as gypsum or anhydrite. Sulphates, when present in high concentrations affect the drinkability and use of waters for certain industrial processes.

In the Big Creek basin, sulphate concentrations are generally low in most waters. In overburden wells the concentrations range from 4 to 341 ppm but are usually less than 100 ppm in most cases. Wells 47 and 89 in Burford Township end in the overburden just above the bedrock and show concentrations of 341 and 1180 ppm, respectively. The quality of water from these wells may reflect leaching of sulphate minerals from gypsum and anhydrite deposits in the Salina Formation present in the area. Sulphate concentrations in wells shallow in the bedrock are generally similar to those in overburden wells. Concentrations of 1000 ppm or more can be expected in waters encountered in deep wells in the bedrock, especially wells that penetrate the Salina Formation. Sulphate concentrations in surface water range from 43 to 141 ppm, but are usually less than 80 ppm. The effects of ground-water discharge are apparent. Sulphate generally constitutes 10 to 40% of the anion concentrations. Sulphate concentrations are shown in Figure 43.

Chloride

Dissociated chloride ions occur in dilute solutions when chlorine, a member of halogen group of elements, is present. The most important sources of chloride in natural waters are associated with sedimentary rocks and evaporite deposits. Connate water or water entrapped in sedimentary rocks may contain abundant chlorides. Some evaporite beds are pure sodium chloride and are abundant sources of chloride. Chlorides are in great abundance in oceanic waters. Chlorides are present in all natural waters but in many areas the

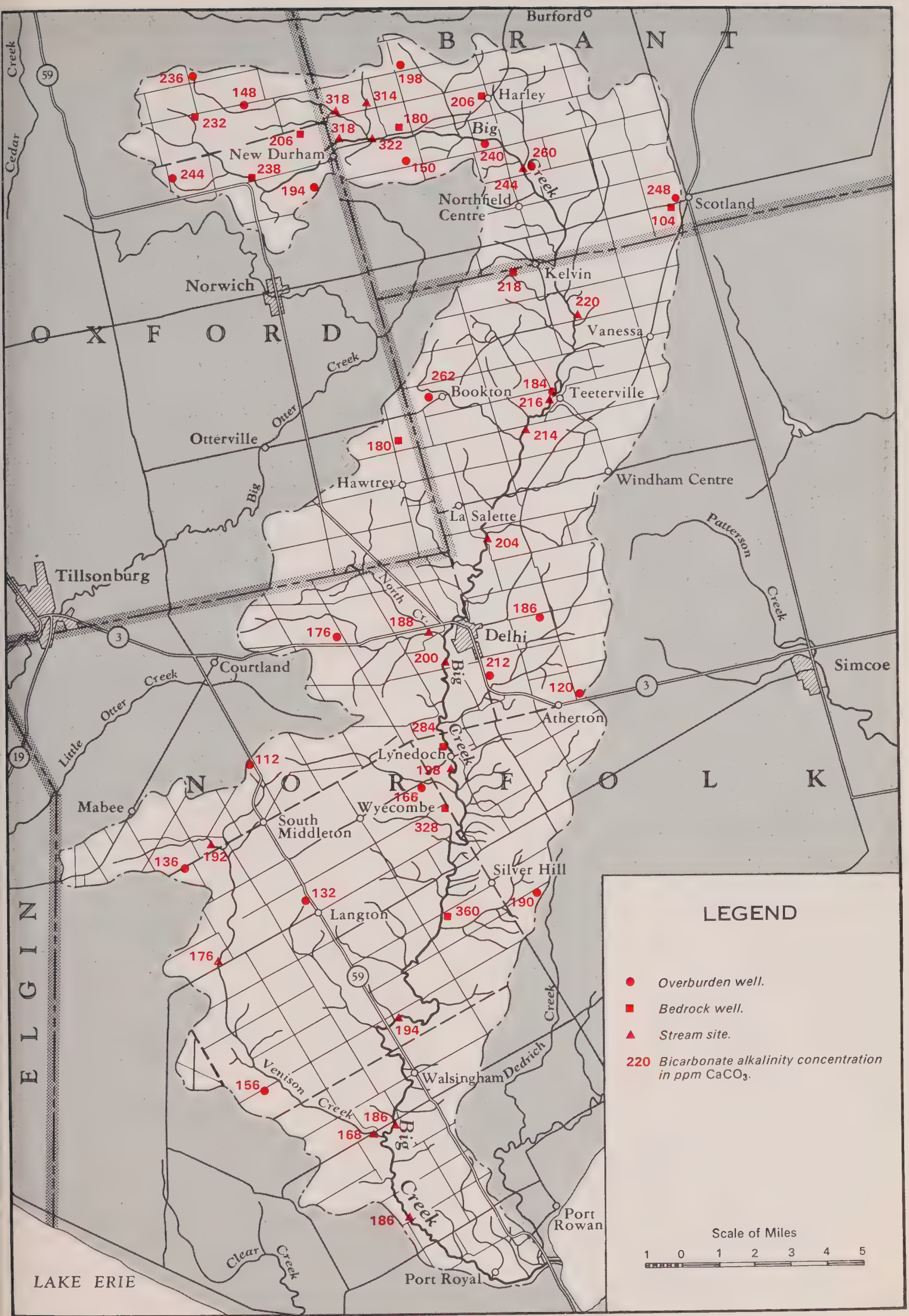


Figure 42. Bicarbonate alkalinity concentration in surface water and ground water, Big Creek basin, 1964.

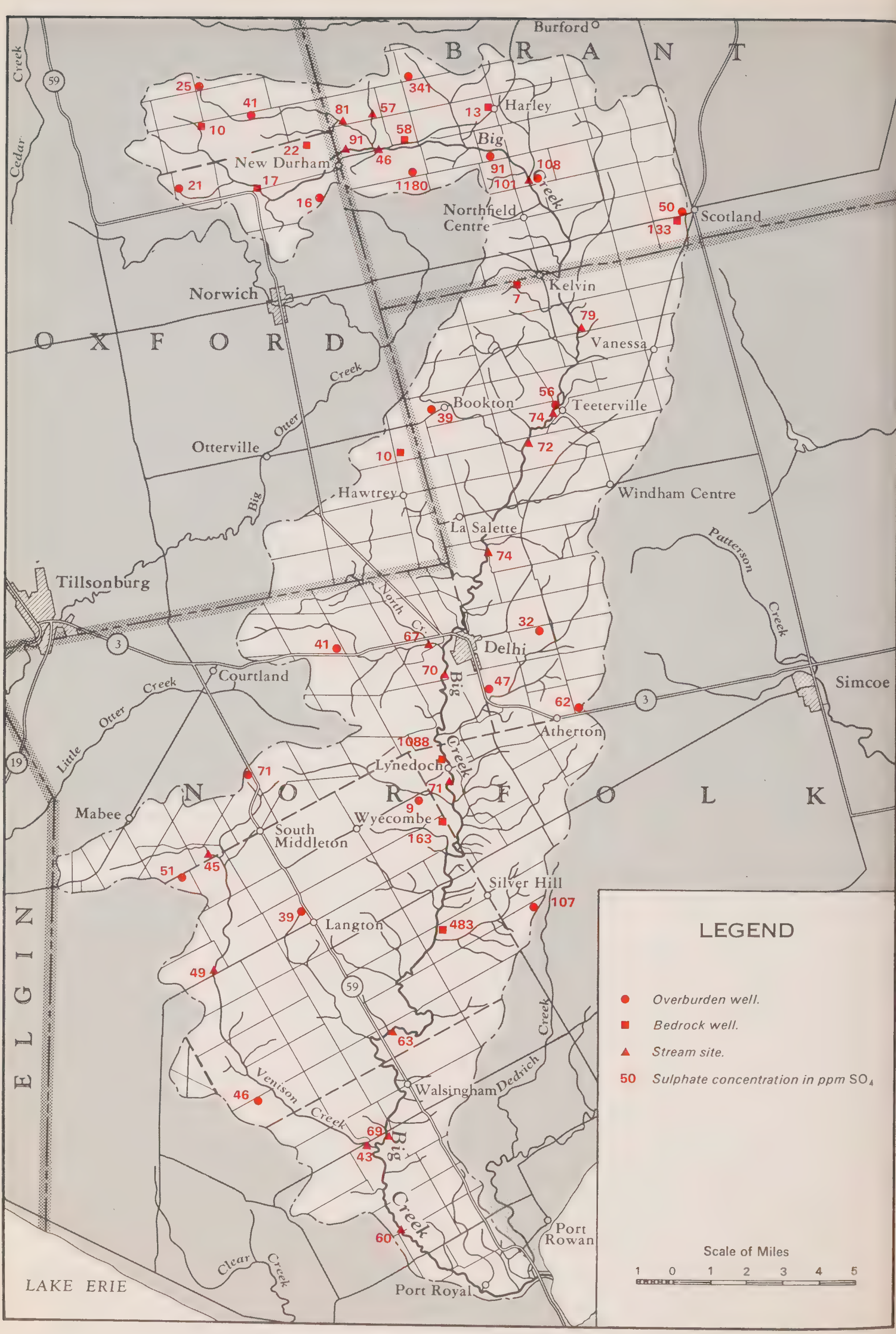


Figure 43. Sulphate concentration in surface water and ground water, Big Creek basin, 1964.

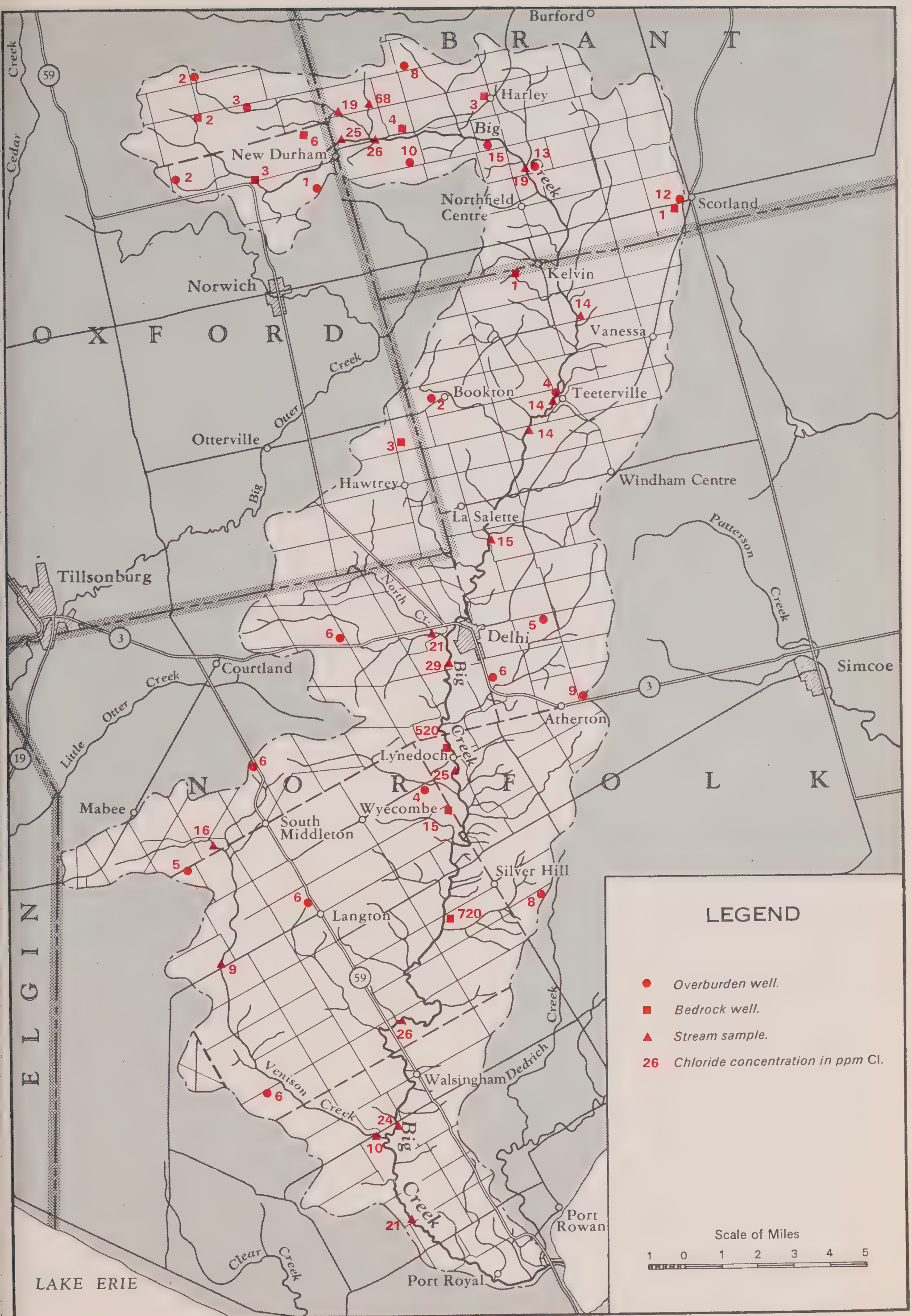


Figure 44. Chloride concentration in surface water and ground water, Big Creek basin, 1964.

amounts are usually small. Chlorides are also indicators of unnatural conditions brought about by pollution.

In high concentrations chlorides impart a salty taste to water and are hazardous to the health of humans and plants in extreme concentrations.

In the Big Creek basin chloride concentrations range from 1 to 84 ppm but are usually less than 15 ppm in ground-water samples from wells in the overburden and shallow in the bedrock. In deep wells in the bedrock, concentrations of 500 to 700 ppm are present and are probably associated with the evaporite deposits in the Salina Formation. Chloride concentrations in surface water samples are usually less than 15 ppm. Repetitive sampling at station S-3 showed fluctuations of over 50 ppm in the concentration. This probably reflects unnatural conditions brought about by contamination.

Chloride concentrations generally constitute less than 15% of the anion concentration. Chloride concentrations are shown in Figure 44.

Nitrate

Nitrate is a form of oxidized nitrogen and is the principal form of oxidized nitrogen in natural waters. Generally it is present only in minor amounts in rocks. Certain plants and plant debris may add nitrates to natural waters but are also a minor source. The activities of man and man-made wastes are generally regarded as the main sources of nitrate in natural waters. Nitrates are readily soluble in water and their presence in natural waters are generally an indication of pollution.

In the Big Creek basin nitrate concentrations are absent in most ground-water samples. A few samples, however, show concentrations of up to 10 ppm as nitrogen. These samples were usually taken from shallow wells in the surface sand deposit. Surface-water samples generally show concentrations of less than 1.0 ppm as nitrogen. The presence of the nitrate may reflect the presence of man-made wastes or fertilizers.

Iron

Iron is one of the most abundant constituents of rocks. The amount present in natural waters is usually very small in comparison to other constituents and is a nuisance rather than a health hazard.

In the Big Creek basin the iron concentrations range from 0.1 to almost 6.0 ppm in ground-water samples. The iron content in waters from the surface sand is generally less than 0.3 ppm but tends to exceed this amount in deeper overburden and rock wells. In some samples high concentrations may reflect iron that was added to ground water from contact with well casings. Concentrations in surface-water samples are also highly variable and may reflect improper sampling techniques or inadequate samples. Iron concentrations are shown in Figure 45.

Hydrogen Sulphide

Hydrogen sulphide, like sulphate, is a compound of sulphur and is generally derived from the oxidation of sulphides of heavy minerals. Hydrogen sulphide in natural water is readily recognizable by its "rotten egg" odour and affects the usability of water, even in minor concentrations.

Hydrogen sulphide concentrations were not analyzed in water samples in the Big Creek basin. Its presence is reported in well records which show that

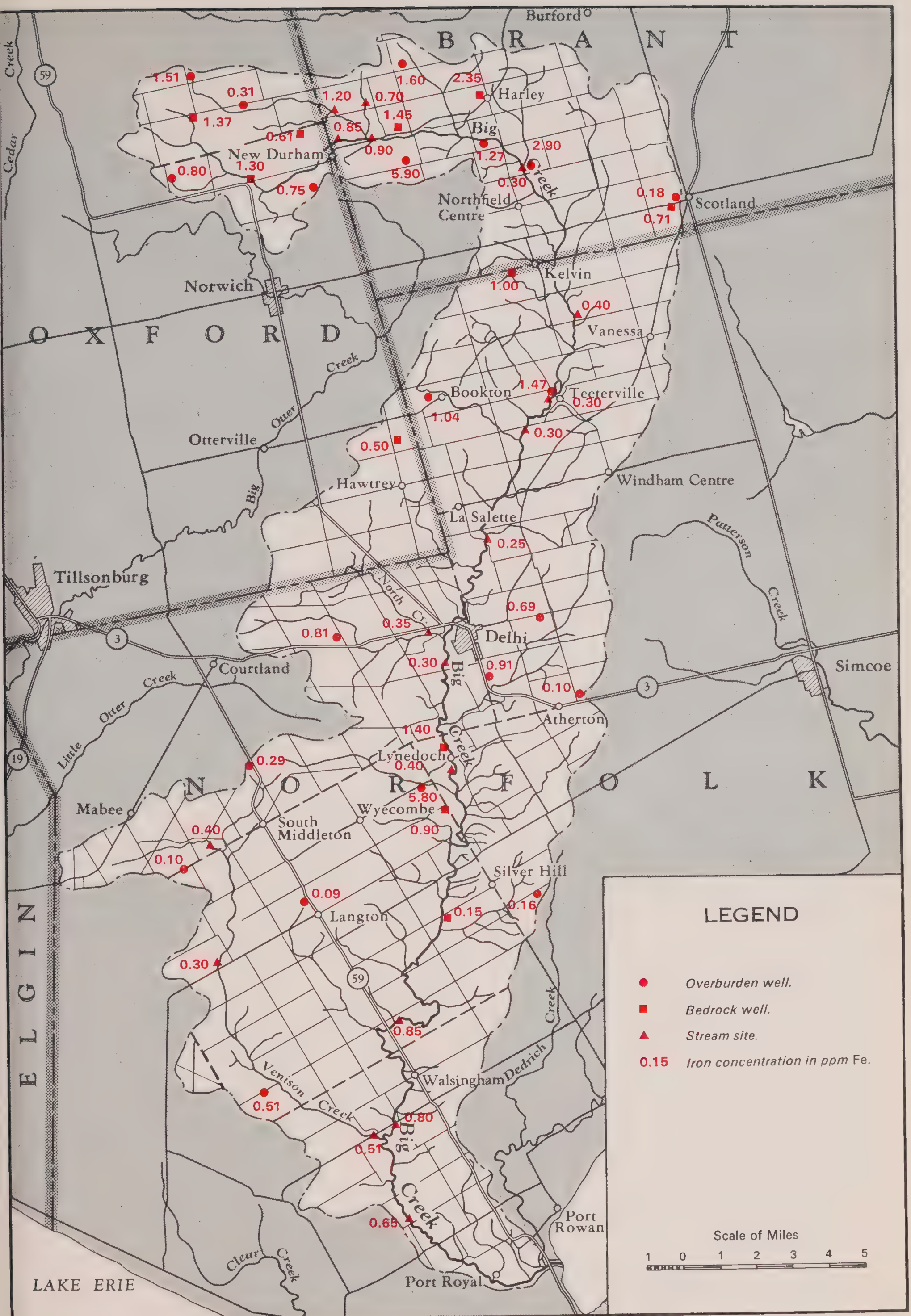


Figure 45. Iron concentration in surface water and ground water, Big Creek basin, 1964.

at least one-third of all rock wells contain hydrogen sulphide, some at very shallow depths in the rock. Wells in the basin where the presence of hydrogen sulphide has been reported are shown in Figure 46.

Silica

Silica is the oxide of silicon, one of the most abundant elements in many types of rocks. It is not readily soluble in water and generally occurs in natural waters in concentrations of less than 30 ppm. In ground-water and surface-water samples in the Big Creek basin concentrations range from 8 to 11 ppm. Its significance in natural waters is that it may be an incrustant.

Hydrogen-Ion Concentration (pH)

The pH or hydrogen-ion concentration of a solution is an indicator of whether the solution has acidic or basic properties, with values greater than 7 indicating basic properties, and values less than 7, acidic.

The pH analyses on all water samples taken in the Big Creek basin were conducted in laboratory facilities. It can only be assumed that they reflect the actual concentrations present at the sampling point. Values of pH range from 7.1 to 8.2 for all samples, which is a common condition for most natural waters.

Hardness

The hardness of natural water is generally associated with the effects observed in the use of soap; the harder the water the greater the soap-consuming power of the water. Hardness in this sense is derived mainly from the effects of calcium, magnesium carbonate and bicarbonate.

Hardness usually becomes objectionable for most domestic purposes when present in concentrations greater than 100 ppm.

In the Big Creek basin the total hardness ranges from 108 ppm to 1620 ppm in ground-water samples, but is usually less than 300 ppm in most, especially those from overburden sources. Wells ending near the bedrock surface in the northern part of the basin often show higher levels of hardness. These, like deep bedrock wells, may be reflecting the presence of calcium sulphate minerals in the bedrock. The hardness in surface-water samples generally ranges from 200 to 300 ppm. Hardness concentrations are shown in Figure 47.

Total Dissolved Solids

Total dissolved solids are the total concentration of dissolved material in water. Concentrations may vary widely in natural waters with concentrations in excess of 500 ppm often being considered undesirable. Water samples from ground- and surface-water sources in the Big Creek basin generally contain less than 500 ppm total dissolved solids. Water from deep rock wells, however, can be expected to have concentrations in excess of 500 ppm or even 1000 ppm. Total dissolved solids concentrations are shown in Figure 48.

Specific Conductance

Specific electrical conductance is the ability of a substance to conduct an electrical current. In water it reflects and therefore is a measure of the amount

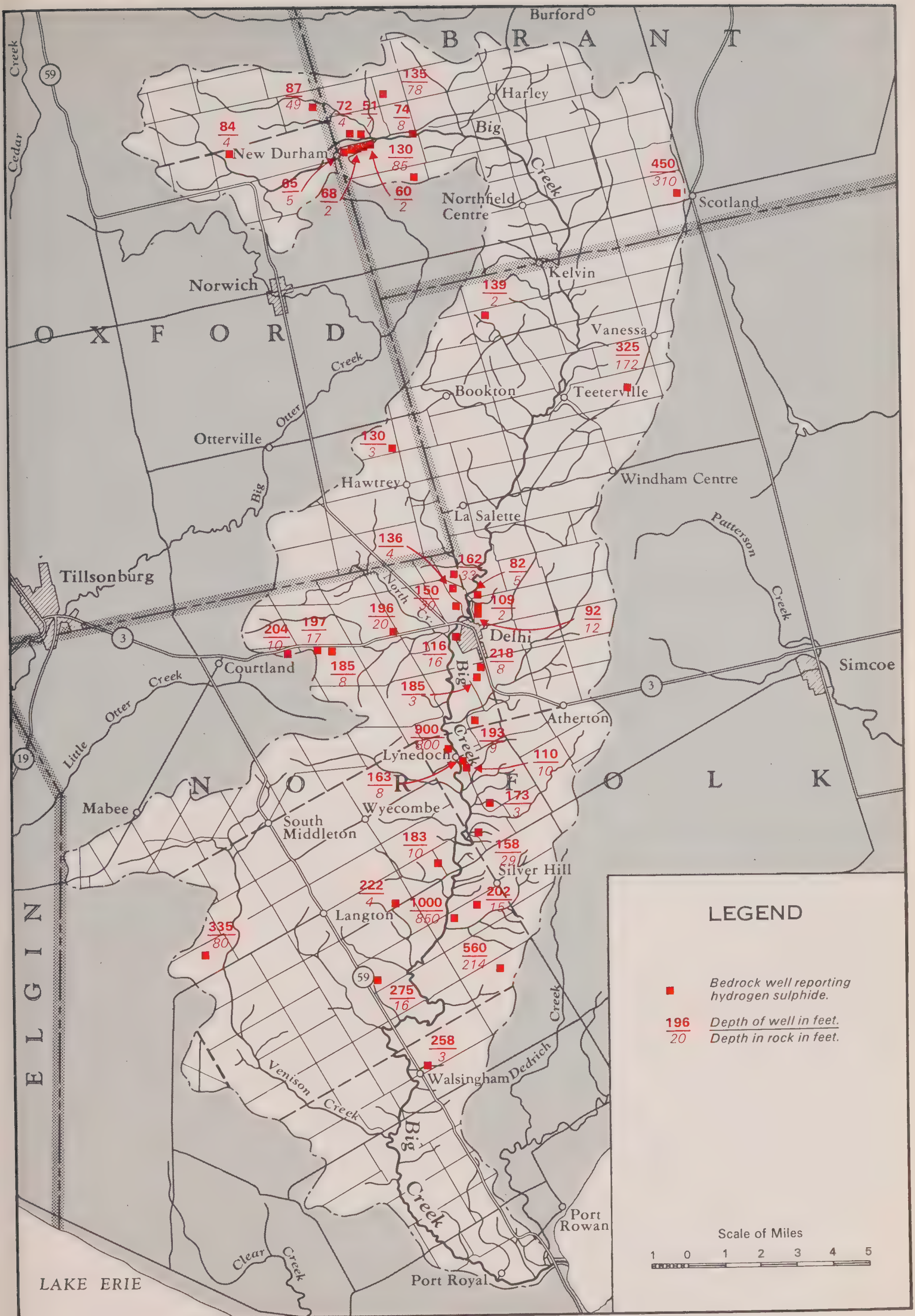


Figure 46. Occurrence of hydrogen sulphide in bedrock wells, Big Creek basin.

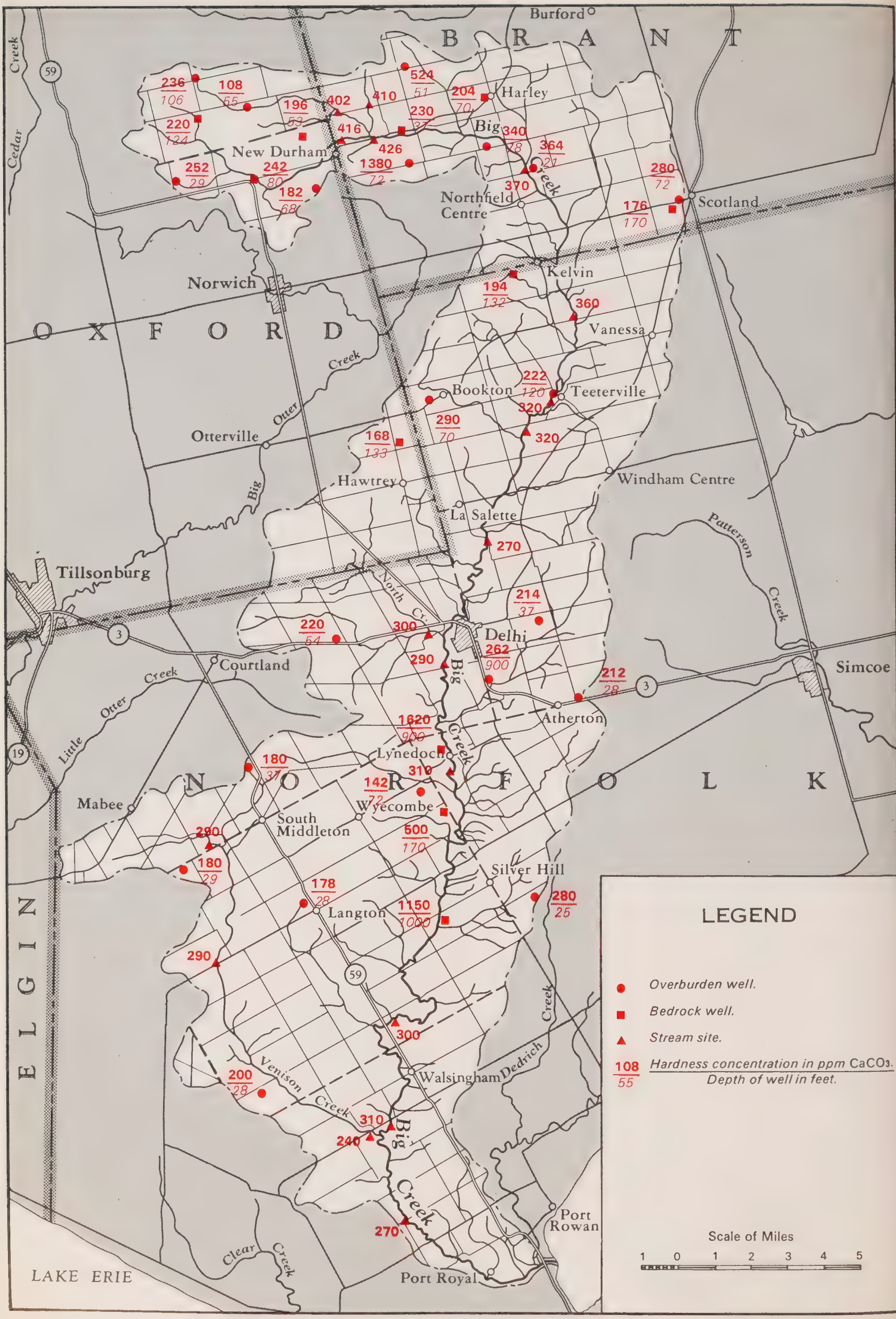


Figure 47. Hardness of surface water and ground water, Big Creek basin, 1964.

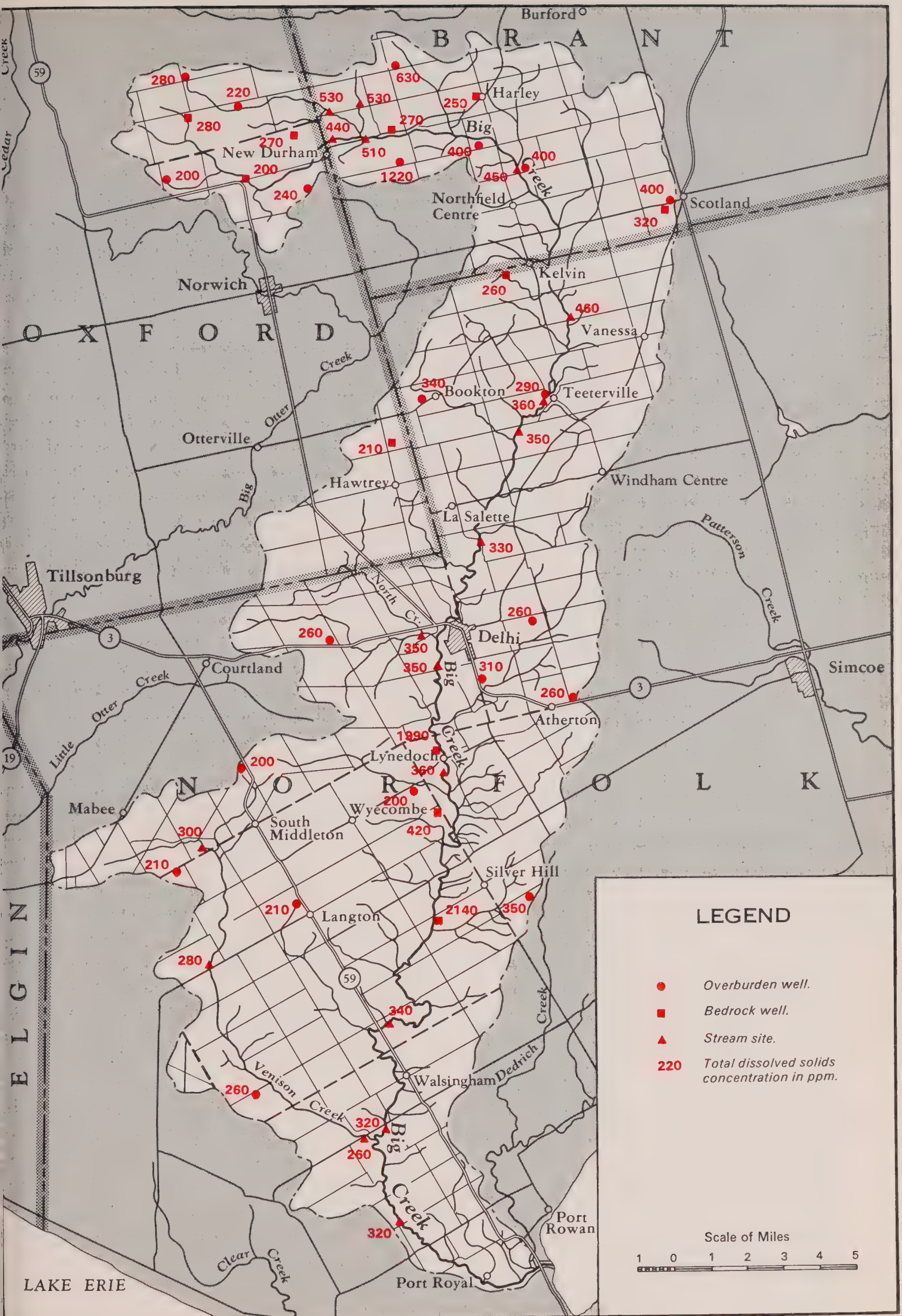


Figure 48. Total dissolved solids concentration in surface water and ground water, Big Creek basin, 1964.

of dissolved mineral. A direct relationship therefore exists between specific conductance and total dissolved solids. On the basis of surface- and ground-water samples in the Big Creek basin, a value of 1.3 was established for the ratio of specific conductance to total dissolved solids.

Classification of Waters

A tri-linear plot, shown in Figure 49, was used to show graphically the chemical composition of 50 water samples in the Big Creek basin and to classify the waters on the basis of their major anion and cation concentrations. Eighteen samples were taken from surface-water sources and 32 from ground-water sources, of which 21 were from overburden wells and 11 from bedrock wells.

Forty-five of the samples fall into the calcium-magnesium bicarbonate section of the diagram. The remaining 5 fall into the calcium-magnesium sulphate section.

The five samples in the calcium-magnesium sulphate section are all from ground-water sources; 3 from the bedrock and 2 from gravel immediately above the bedrock. The 2 overburden wells are wells 47 and 89 and are located in Burford Township. One of the rock wells, Well 111, is also located in Burford Township. The other two rock wells are former gas and oil wells located in Charlotteville and North Walsingham townships. All five wells probably reflect the presence of sulphate materials in the bedrock formations.

Of the 45 samples in the calcium-magnesium bicarbonate section, 15 are from surface-water sources, 19 from overburden ground-water sources and 8 from bedrock ground-water sources. The noticeable cluster of the overburden ground-water samples and the surface-water samples implies a direct relationship between the two waters. The ground-water samples from bedrock wells show a significantly different distribution than those from overburden wells in the proportion of bicarbonate to sulphate and chloride and the somewhat higher proportions of sodium. The composition of waters from bedrock wells is probably a reflection of the availability of these constituents at depth in the bedrock. The more equal proportion of bicarbonate to sulphate and chloride in overburden water samples is probably a reflection of the composition of soils in the basin.

Hydrologic Correlations

Some attempt was made to correlate the chemical quality of ground water with geology, with ground-water flow patterns and with surface water. Such correlations are by no means simple and therefore, because of time and data restrictions, only some general observations were possible.

The relationship between ground-water quality and geology is, in essence, discussed under the preceding section. In general, there appears to be no noticeable difference in the quality of ground water at various depths in the overburden. Considering that much of the overburden consists of fluvial and lacustrine deposits of similar composition, a difference in quality would not be expected.

Differences in overburden and bedrock waters are more apparent. Although ground water from the overburden and shallow bedrock zones is calcium bicarbonate in nature, a subtle difference in the proportion of bicarbonate to sulphate and chloride and sodium to calcium and magnesium is suggested, and may reflect a greater abundance of carbonate in the bedrock formations.

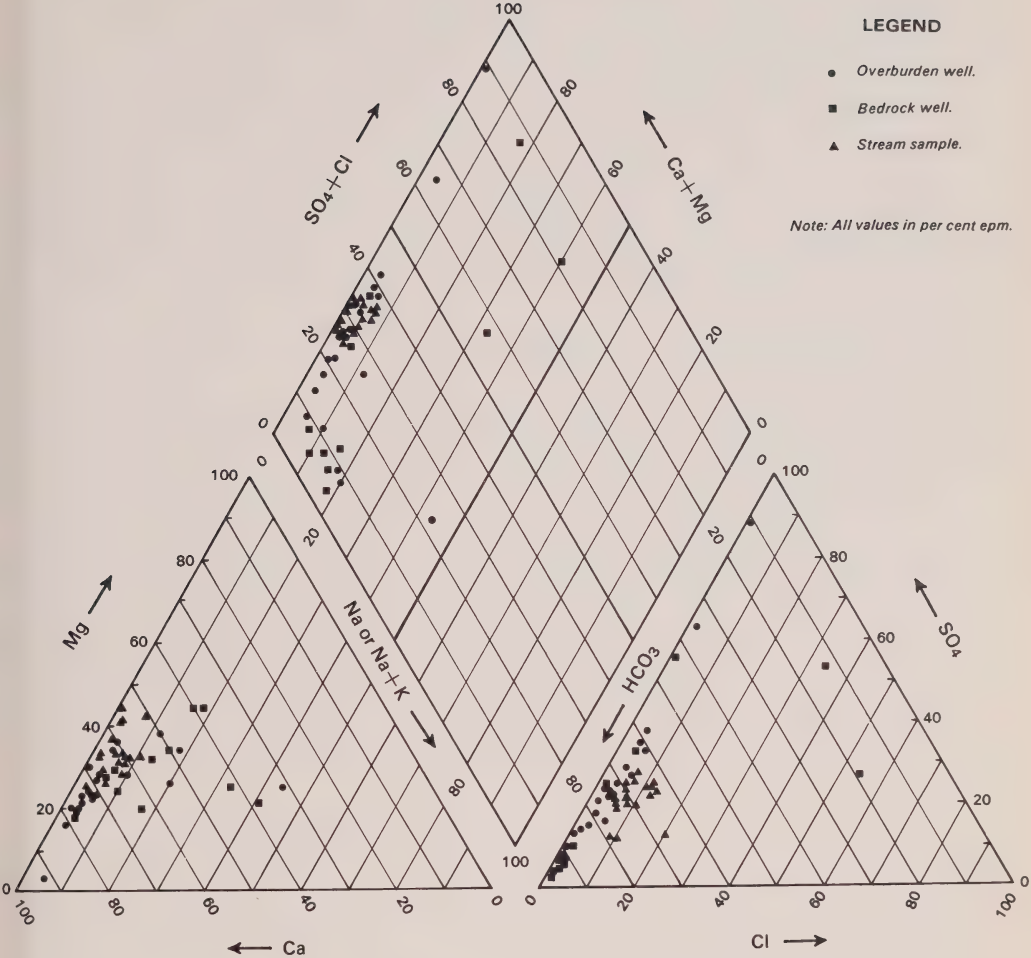


Figure 49. Chemical composition of surface water and ground water, Big Creek basin, 1964.

At greater depths in the bedrock a change to calcium sulphate waters is in evidence, probably because of the presence of sulphate and chloride-bearing minerals.

The relationship of quality and flow pattern is based on the concept of the change of water quality down the flow direction. Subtle changes in the hydrostatic heads in water-table and artesian aquifers and the horizontal stratigraphy in the overburden imply a strong lateral component of ground-water flow. Under the circumstances changes in quality with depth would be expected to be subtle, which is, in fact, the case. More obvious differences in the quality in overburden and bedrock sources tend to bear out the concept.

The relationship between ground-water and surface-water quality is perhaps the most obvious. Surface samples were taken during periods of low flow, at which time all flow was believed to consist of ground-water discharge. The similarities in the concentrations of the major cations and anions in stream samples and overburden ground-water samples reflect the direct relationship.

Suitability of Waters for Drinking Purposes

The suitability of water for drinking purposes is always an important consideration of water resources. While chemical aspects are important, the physical and bacterial aspects should not be overlooked.

Certain chemical constituents are hazardous to health and therefore mandatory limits must be observed.

Other constituents are nuisances rather than hazards, and, while preferred limits are desirable, the availability of water and the costs of treatment may dictate that these limits be exceeded. Routine analyses performed on samples collected for this survey provide a general indication of chemical suitability of water, but do not provide information on hazardous elements. The presence and recognition of contaminants that may affect the chemical or physical quality of the water must be given due regard before a water can be considered fit to drink.

Desirable standards for certain common chemical constituents in drinking water are as follows (OWRC, 1967):

Constituent	Upper Limit of Concentration (ppm)
Sulphate	250
Chloride	250
Nitrate (NO_3)	45
Iron	0.3
Total dissolved solids	500

In the Big Creek basin natural waters from most sources generally meet the desirable standards for these constituents and can be considered as generally acceptable in chemical quality for drinking-water purposes. The iron content appears to be highly variable and may, in part, be due to other than natural conditions.

The chemical quality of ground water from bedrock wells is highly variable and in some instances cannot be considered suitable for drinking purposes. Most wells shallow in the bedrock often have acceptable quality

water but hydrogen sulphide is common in this water-bearing horizon, often in sufficient concentration to cause rejection of the water supply. This condition appears to exist throughout most of the basin. In local areas in the northern part of the basin water from wells shallow in the bedrock can contain concentrations of sulphate or chloride in excess of the desirable limit. Wells that penetrate deep into the bedrock, particularly in the Salina Formation, can be expected to encounter water with concentrations of sulphate and chloride far in excess of the desirable limits.

Suitability of Waters for Irrigation Purposes

The extensive use of water in the Big Creek basin for irrigational purposes necessitated a comprehensive understanding of the suitability of the water quality for these purposes. The determination of whether a water is suitable for irrigation has been given a great deal of study and, although certain relationships have been established, there is no assurance that the application of the relationships to the variety of field conditions that may occur will give the results desired.

The determination of the suitability of water for irrigation involves the study of the chemical changes that take place in the soils due to natural chemical processes and due to artificial reactions brought about by the addition of irrigation water. The phenomenon of base exchange is involved and relates to the loss of permeability and fertility in soils through the build-up of harmful salts in the soils. Sodium, calcium and magnesium are the main cations involved with sodium replacing calcium and magnesium. The concentration of sodium in the soil is a significant factor in determining whether a water is suitable for irrigation and several relationships have been developed in this regard. Five such relationships that have been developed are: percentage sodium, sodium-adsorption-ratio (SAR), residual sodium carbonate (RSC), percentage sodium-electrical conductivity, and sodium hazard (sodium-adsorption-ratio)-salinity hazard (electrical conductivity). The initial two relationships are included in the discussion of the latter three.

Percentage Sodium — Electrical Conductivity

Percentage sodium and electrical conductivity in irrigation waters are important criteria in classifying the suitability of the waters. Wilcox (1948) presented a classification based on these criteria.

Percentage sodium is calculated from:

$$\%Na = \frac{Na^+}{Na^+ + K^+ + Ca^{++} + Mg^{++}} \times 100$$

where ionic concentrations are expressed in epm.

The electrical conductivity or specific conductance is expressed in micromhos per cubic centimeter at 25°C and reflects the concentration of dissolved solids.

A classification of 50 water samples from the Big Creek basin with regard to their suitability for irrigation according to this relationship is shown in Figure 50.

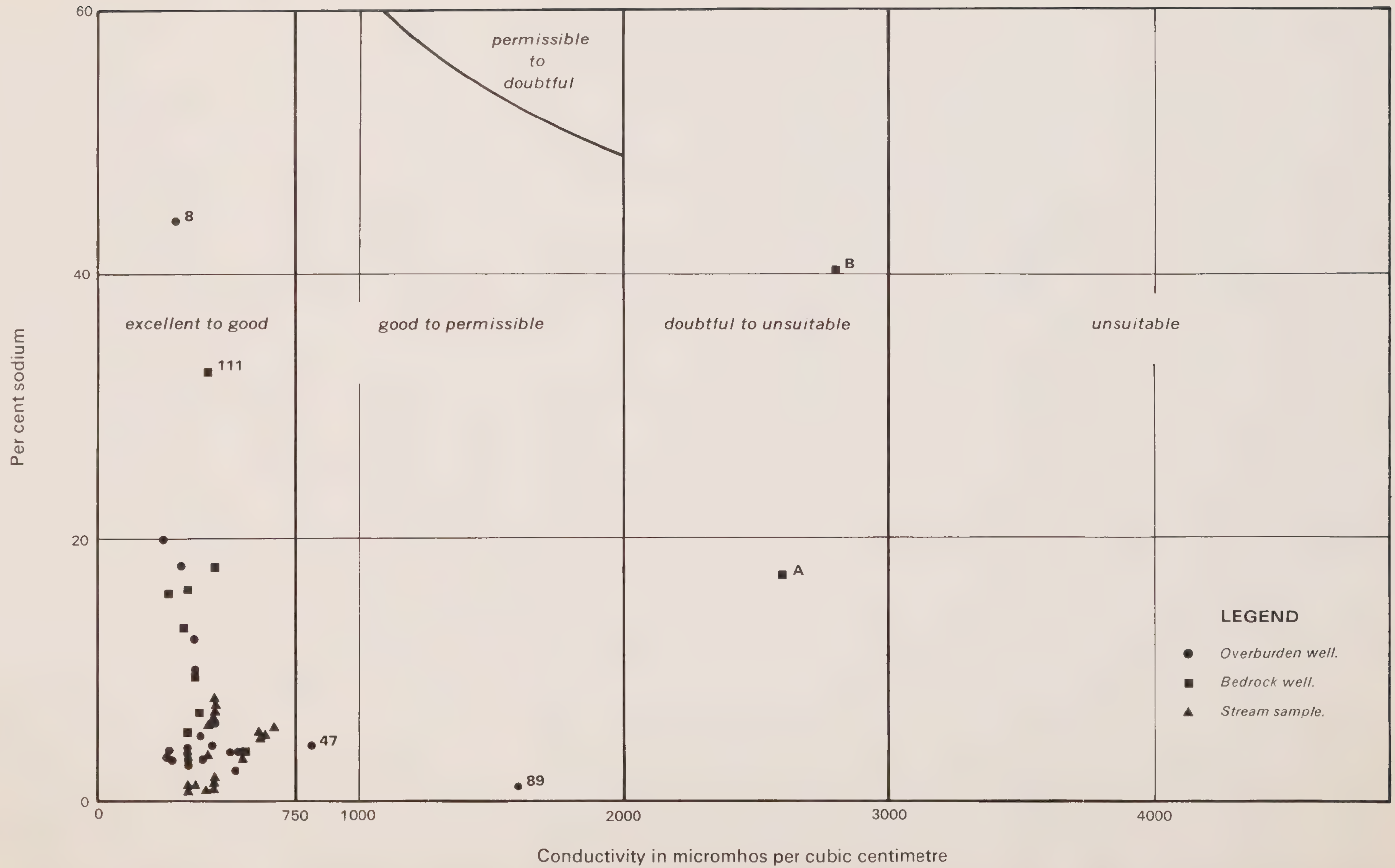


Figure 50. **Classification of surface water and ground water with respect to suitability for irrigation, Big Creek basin, based on percentage of sodium and conductivity (after Wilcox, 1948).**

All of the samples fall into the excellent to good class with the exception of samples from wells 47, 89, A and B. The water from wells 47 and 89 may be permissible for irrigation but the suitability is affected by the presence of abundant concentrations of sulphates. The water from wells A and B are unsuitable for irrigation because of excessive concentrations of sulphates and chlorides. These four cases reflect the presence of lower quality water in the bedrock.

Residual Sodium Carbonate (RSC)

This concept, as an approach to the evaluation of irrigation waters, was presented by Eaton (1950) and is an indirect approach to the sodium hazard. It is based on the premise that if all calcium and magnesium in the applied irrigation water precipitates as carbonates in soils and if carbonate and bicarbonate exceed calcium and magnesium, the difference is residual sodium carbonate (RSC). This may be expressed as follows:

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

where ionic concentrations are expressed in epm.

A classification of 50 water samples from the Big Creek basin based on the above concept is shown in Figure 51. All of the samples have an RSC less than 1.25 epm and are therefore considered safe for irrigation according to this parameter. Samples having RSC values between 1.25 and 2.50 epm are considered marginal while samples having RSC values above 2.50 epm may be considered unsuitable for irrigation.

Sodium Hazard — Salinity Hazard

The sodium-salinity hazard relationship is probably the most important method in evaluting the suitability of waters for irrigation because many parameters that contribute to the suitability of the waters are considered. The sodium hazard is expressed in terms of the sodium-adsorption-ratio (SAR) and the salinity hazard in terms of the electrical conductivity.

The sodium-adsorption-ratio (SAR) expresses the sodium hazard in terms of the sodium, calcium and magnesium relationship in the base exchange process through the following mathematical formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where ionic concentrations are expressed in epm.

The salinity hazard depends on the concentration of dissolved solids and is expressed in terms of the electrical conductivity of the water.

A classification, based on the sodium-salinity hazard, has been developed by the U. S. Salinity laboratory staff (1954). In the classification 4 classes of waters are recognized with respect to each of the hazards.

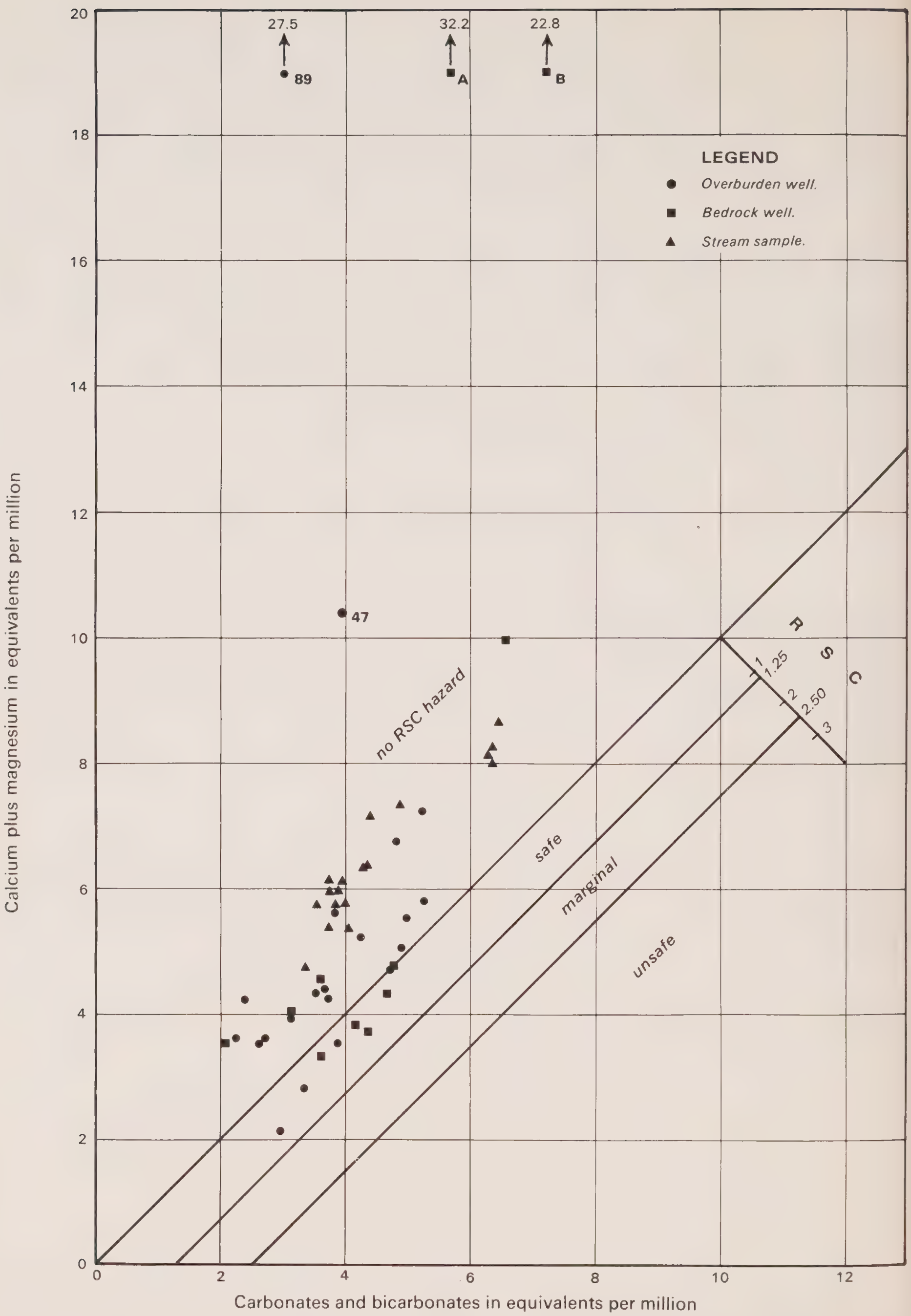


Figure 51. Classification of surface water and ground water with respect to suitability for irrigation, Big Creek basin, based on residual sodium carbonate (RSC) (after Eaton, 1950).

The sodium-hazard classes and water characteristics are as follows:

Class S1. **Low-sodium water** can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium sensitive crops may accumulate injurious concentrations of sodium.

Class S2. **Medium-sodium water** will present an appreciable sodium hazard in fine-textured soils having high-cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used in coarse-textured or organic soils with good permeability.

Class S3. **High-sodium water** may produce harmful levels of exchangeable sodium in most soils and will require special management, good drainage, high-leaching and organic matter additions.

Class S4. **Very high-sodium water** is generally unsatisfactory for irrigation purposes, except under special circumstances.

The salinity-hazard classes and water characteristics are as follows:

Class C1. **Low-salinity water** can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Class C2. **Medium-salinity water** can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

Class C3. **High-salinity water** cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Class C4. **Very high-salinity water** is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances.

The values of SAR and conductivity for 50 water samples from the Big Creek basin are plotted in Figure 52 in accordance with the sodium-salinity hazard classification. With the exception of water samples from 4 wells, all of the points fall into the S1-C2 class. The 46 points in this class indicate that the water in streams and in most wells is generally suitable for irrigation. All the water samples generally have a low-sodium hazard because of low SAR values. Conductivity values, however, are significantly higher in wells 47, 89, A and B than in other samples and therefore indicate an increased salinity hazard for these samples. Wells 47 and 89 are overburden wells and fall into the C3 class and wells A and B are deep rock wells and fall into the C4 class. The water from these wells could present problems if used for irrigation. The water from wells 47 and 89 also has a high sulphate content and the water from wells A and B high sulphate and chloride contents. The four samples reflect the variable water-quality conditions that exist in the bedrock and locally in the overburden deposits immediately above it.

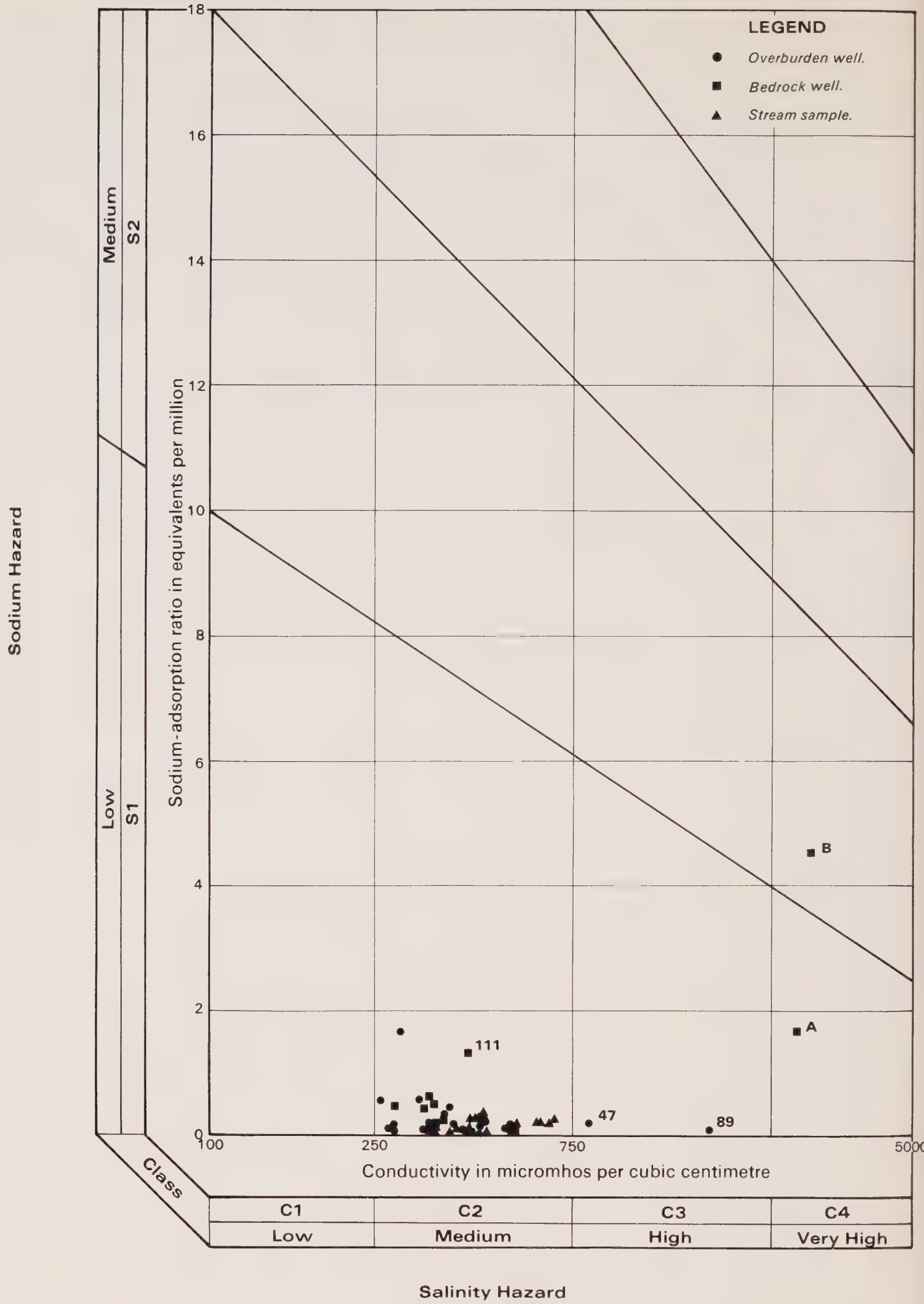


Figure 52. Classification of surface water and ground water with respect to suitability for irrigation, Big Creek basin, based on sodium and salinity hazards (after U.S. Salinity Lab. Staff, 1954).

WATER USE AND DEVELOPMENT

In the Big Creek basin, water is used primarily for irrigation, rural domestic, livestock, and municipal purposes. In the following paragraphs, these uses are described as to the quantity of water used, location of usage, time and duration of usage and the sources of water.

Water can be used in place or withdrawn for use elsewhere. In-place uses of water generally result in no loss of the resources to the basin. Withdrawal uses, however, may be consumptive or non-consumptive and may involve losses in the resource. Irrigation is a major use of water in the basin and because of its highly consumptive nature, a detailed description of this use is given.

In the final paragraphs, suggestions are given regarding future development of the water resources of the basin.

Present Water Use

Sources and Methods of Extraction

Three basic sources of water are available in the basin. They are ground and surface waters and, to a much smaller extent, intercepted rainwater. Ground water is water temporarily stored below the land surface and is constantly moving towards a natural discharge area. Surface waters include the waters in streams, rivers, ponds and lakes. Intercepted rainwater is collected in cisterns or in ponds not connected to a watercourse or to the ground-water reservoir.

A variety of techniques and methods are used to extract ground and surface water for domestic, stock, muncipal and irrigation uses in the Big Creek basin. Purpose, water requirements, economic factors, water-quality considerations and the adequacy and the convenience of the source determine whether a ground- or surface-water source is used.

Because of the favourable hydrogeologic conditions in much of the basin, ground water is used broadly and is extracted by means of wells and dugout ponds. In sandy areas, shallow drilled wells or sand points are common. Conditions in these areas are also favourable for the excavation of ponds from which sizeable quantities of water can be withdrawn economically. In the more clayey areas, dug wells are common, but as water requirements increased the adequacy of the wells decreased and the drilling of wells to deeper, more adequate zones resulted. Springs are common along the sides of the deep stream valleys, but their use is minimal.

Surface water is extracted by means of intakes into ponds and streams. Three main types of ponds are common in the basin: on-stream, off-stream and dugout. An on-stream pond where storage on the stream has been created through a dam or where the stream's sides and bottom have been enlarged, supplies water directly from the stream. An off-stream pond is supplied by a stream through a bypass ditch or canal. A dugout pond is an excavation ending above or below the water-table. In the Big Creek basin most dugout ponds are directly connected to ground-water zones. Water is also taken directly from

streams with little or no modification to the streambed. Usually, water is extracted from natural depressions in the streambed where the volume of surface-water storage is large.

Infiltration wells are wells located at an edge of a pond and which have an artificial gravel pack to filter the waters collected in the pond. Such wells are used at places in the clayey southern areas in the basin where surface- and ground-water sources are unavailable. The collection of rainwater in cisterns is also practised in these areas.

Municipal Water Use

The Town of Delhi is the only municipality in the basin having a municipal water-supply system. Its water is obtained from North Creek and from a spring on the east bank of Big Creek immediately south of town. The intake in North Creek is located in the reservoir created by the Lehman Dam which was completed in 1965. The water from the spring is collected in a reservoir from which it is pumped into the municipal system. The yield from the spring supply is variable. The amount of water produced from the spring increased from 1964 to 1968.

The statistics on the municipal use of water from both sources of supply for 1964 are shown in Table 30. The North Creek supply provided about 66 per cent of the annual supply and the spring supply, the remainder. The total annual water use for 1964 was 140.25 million gallons, an average of 0.38 million gallons per day (mgd). The minimum and maximum monthly consumptions were 0.30 and 0.59 mgd, respectively. Nearly all of the water used is returned to Big Creek via a sewage treatment plant.

Industrial Water Use

All known industries established in the basin are located in Delhi. Except for two, the operations are essentially dry. These two industries are supplied with water from Delhi's municipal water-supply system and probably use up to 0.04 mgd. Most of this water is used for cooling and rinsing and is discharged to Big Creek through a storm drain. The remainder is discharged to Big Creek via Delhi's water pollution control plant.

Rural-Domestic Water Use

The water used by the rural population in the basin was estimated on the basis of an assumed per capita consumption of 50 gallons per day. At this rate, the mean daily consumption is about 0.60 mgd and the total annual consumption about 220 million gallons. Nearly all of this water is extracted from ground-water sources by means of drilled and dug wells and sandpoint systems. Some is obtained from cisterns and infiltration wells. Much of the water is returned to the basin through private disposal systems.

Livestock Watering

The water used for livestock water in 1964 is based upon 1966 livestock population figures estimated from DBS sources for the basin and upon the following water consumption rates (Hore, 1968):

Table 30. **Municipal Water Pumpage Statistics, Town of Delhi, 1964**

Month	North Creek Supply				Spring Supply				Combined Supplies	
	Total (million gallons)	Average Day (mgd)	Max. Day (mgd)	Min. Day (mgd)	Total (million gallons)	Average Day (mgd)	Max. Day (mgd)	Min. Day (mgd)	Total (million gallons)	Average Day (mgd)
January	6.10	0.20	0.33	0.10	3.16	0.10	0.36	0.00	9.26	0.30
February	5.60	0.19	0.34	0.01	3.38	0.12	0.29	0.00	8.98	0.31
March	5.42	0.17	0.37	0.01	4.18	0.14	0.33	0.00	9.60	0.31
April	5.43	0.18	0.34	0.06	3.78	0.13	0.36	0.00	9.21	0.31
May	8.73	0.28	0.44	0.08	3.46	0.11	0.36	0.00	12.19	0.39
June	11.33	0.38	0.81	0.01	4.09	0.14	0.30	0.00	15.42	0.51
July	14.03	0.45	0.72	0.19	4.14	0.13	0.30	0.00	18.17	0.59
August	7.85	0.25	0.45	0.01	4.34	0.14	0.36	0.00	12.18	0.39
September	8.40	0.28	0.46	0.05	4.66	0.16	0.38	0.00	13.06	0.44
October	6.75	0.22	0.40	0.03	4.33	0.14	0.32	0.00	11.08	0.35
November	6.66	0.22	0.35	0.03	3.91	0.13	0.33	0.00	10.57	0.35
December	5.97	0.19	0.34	0.02	4.56	0.15	0.35	0.00	10.53	0.34
Annual Total or Average	92.27	0.25			47.99	0.13			140.25	0.38

Livestock	Amount used in gallons per day
Each producing milk cow	30
Each beef cow	12
Each horse	12
Each hog	1.5
Each sheep	1.5
Each 100 chickens	5

The calculated livestock water consumption is about 0.22 mgd or 82 million gallons per year, which is less than eight per cent of the total water used annually. The water is extracted mainly from dugout ponds, wells and streams and is largely returned to the basin after use.

Irrigation Water Use

Irrigation is practised extensively throughout the basin. The major crop irrigated is tobacco, which is grown on the sandy soils. These soils occupy about 75 per cent of the basin. Tobacco is very sensitive to low moisture conditions and its yield can, therefore, be substantially increased through the application of supplementary irrigation water during dry periods. Much of the irrigation water will be lost to the basin water supply through evapotranspiration by the plants and evaporation from land surfaces. The amount of water applied will vary from farm to farm, from season to season, depending on the local soil-moisture and climatic conditions prevailing during the growing season and the mode of operation of the irrigators.

The information on irrigation water use in the Big Creek basin was obtained from the records submitted to the Ontario Water Resources Commission in accordance with the requirements of permits to take water. The taking of large quantities of water is regulated by permit in the Province of Ontario under The Ontario Water Resources Commission Act. Section 28(a) provides that no person shall take more than a total of 10,000 gallons of water per day from new wells, inlets, diversion or storage works for purposes other than domestic, stock or firefighting without a permit issued by the OWRC.

The total number of permits to take water for irrigation in the Big Creek basin issued by the Commission to May 30, 1964, are listed in Table 31. The table gives a breakdown of the permits by sub-basin and by source from which the water was to be withdrawn. In most instances the permits are issued for the taking of water from either a ground- or surface-water source; however, in some instances the source is combined and undifferentiated. Ground water is extracted from dugout ponds, well-point systems and wells. These dugout ponds are connected directly to the water-table. Surface water is extracted from streams, on-stream ponds, and off-stream ponds. The locations of water takings authorized by permit are shown in Map 2706-6.

Records of water taken during the summer season of 1964 by permittees in the Big Creek basin above the Kelvin and Delhi streamflow gauging stations and in the North Creek basin are also shown in Table 31. About 50 per cent of the permittees submitted records of water takings, but a significant number reported that no water was taken. About 96 per cent of the returns contained sufficient detail to calculate the daily water takings. Records were also received for takings in the Venison Creek basin and in the area below the Delhi gauge, however, these data were not tabulated.

Table 31. Number of Water-Taking Permits Issued for Irrigation Purposes to May 30, 1964, and the Number of Water-Takings Reported in 1964, Big Creek Basin

Basin	Number of Permits Issued	Approved Takings by Source			Water Takings Reported in 1964	
		Ground Water	Surface Water	Undifferentiated	Number of Records Received	Number of Records with Takings Reported
Big Creek above Kelvin streamflow gauging station	81	69	8	4	40	23
North Creek	87	53	31	3	45	36
Big Creek above Delhi streamflow gauging station	399	276	110	13	201	169
Big Creek above Walsingham streamflow gauging station	698	440	224	34	*	*
Venison Creek above streamflow gauging station	117	48	60	9	*	*
Entire Big Creek Basin	866	507	309	50	---	---

* Data available but not tabulated.

The computed total amount of water taken for irrigative purposes in the basin in 1964 is presented in Table 32. The data are based on the water-taking records submitted to the Commission for the upper part of the basin and on the assumption that irrigators who did not submit water-taking records, followed similar irrigation practices as those who submitted records. This assumption appears to be realistic and is based primarily on the favourable correlation between the computed amount of water withdrawn and the amount of depletion in streamflow.

Table 32. Computed Total Water Taken for Irrigation, Big Creek Basin, 1964

Basin	All Sources (million gallons)	Ground Water (million gallons)	Surface Water (million gallons)	Undifferentiated (million gallons)
Big Creek above Kelvin streamflow gauging station	26	19	6.7	0.7
North Creek	56	24	31	0.6
Big Creek above Delhi streamflow gauging station	270	160	110	3.3
Big Creek above Walsingham streamflow gauging station	500	260	230	8
Venison Creek above Walsingham streamflow gauging station	88	24	62	2
Entire Big Creek Basin	630	300	320	12

The water withdrawn for irrigative purposes in the basin in the 1964 summer season is estimated to be 630 million gallons.

A better appreciation of the irrigative practices in the Big Creek basin is obtained when the amount of water taken during the course of an irrigation season is expressed in inches of water applied by an individual irrigator to an individual area or farm. To this end a cumulative frequency curve (Figure 53) was prepared showing the number of inches of water applied by farm during the 1964 irrigation period. This curve is based on a sample of 194 farms in the drainage area above the Delhi gauging station and, of these, 162 farms were irrigated.

Irrigative practices in the drainage area above the Delhi gauge are reflected in this curve. Applications of water ranged from 0.2 to 5.6 inches, with 50 per cent of the farms reporting an application of less than 1.3 inches. The average amount of water applied on the total estimated tobacco acreage planted on the 162 farms was about 1.8 inches.

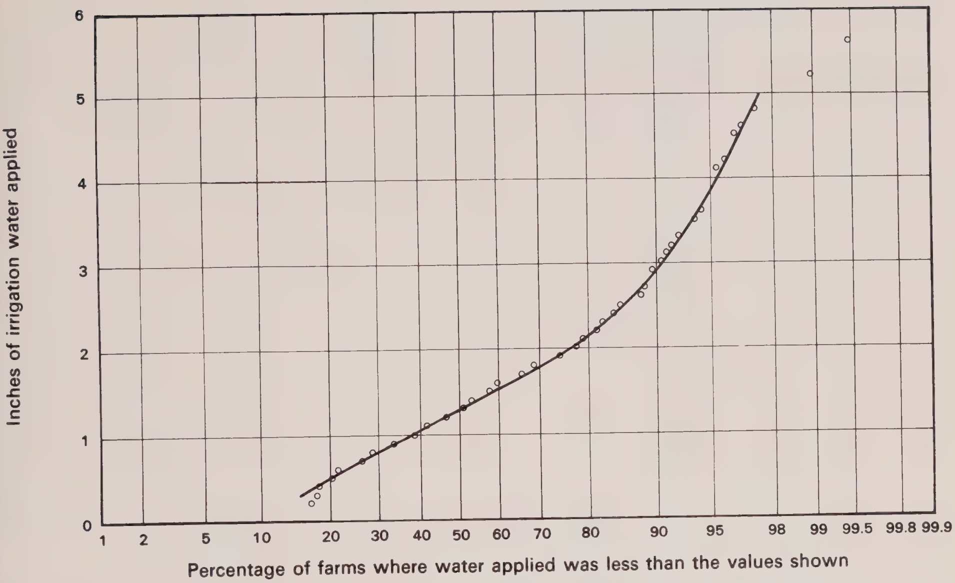


Figure 53. Cumulative frequency curve of irrigation water applied on tobacco crop by individual farm, Big Creek basin, 1964 (based on partial returns for Big Creek basin above the Delhi streamflow gauging station).

The estimated water withdrawn for irrigative purposes in the total Big Creek basin, 630 million gallons, is equivalent to about 1.6 inches over the total estimated tobacco acreage planted. This latter value is about 10 per cent less than that in the sample and reflects the fact that the 1.6-inch average included acreage that was not irrigated in 1964.

At the Delhi Research Station of the Canada Department of Agriculture, 2.93 inches of water were applied during the 1964 summer season. The amount of water applied was in accordance with a soil moisture budget.

The annual soil-moisture conditions in the basin were examined in detail by the OWRC by means of a water balance study, based on the method by Thornthwaite and Mather (1957) and on the typical soil-type occurring at the Delhi Research Station, the Fox soil series, with tobacco as its crop. It was found that a deficiency of about 3.0 inches occurred during the tobacco growing season.

Based on the two methods, tobacco farmers in the area generally applied less water than was necessary to satisfy soil moisture requirements in 1964.

Other crops such as fruits, potatoes and corn are irrigated in the basin. The exact acreages and the amounts of water used are unknown, but are assumed to be relatively small and were not included in the estimates of water used for irrigation.

The relative percentages of irrigation water used in the basin by source and method of extraction are presented below:

Source and Method of Extraction	Percentage of Total Number of Extractions		
Surface Water	33		
Stream (no pond)		20	
On-stream pond		9	
dam			4
no dam *			5
Off-stream pond		4	
Ground Water	67		
Dugout pond		60	
Spring		1	
Well and well-point system		6	

* includes the extractions from Lake Hunger

The amount of water used for irrigation varies widely from year to year. Two major factors determine the water use requirements. The first one, climate, determines whether or not the soil moisture conditions of the upper soil zone are adequate throughout the tobacco growing season for good crop yield. When inadequate, the natural soil moisture can be augmented through the application of irrigation water. The amount applied varies with respect to the development stage of the tobacco plant. When the plants are small the root systems are small and a plant requires less water than when the plant is near maturity. Therefore, not only the number of consecutive dry days, but their occurrence within the growing season, whether late June or early August, will also determine the amount of irrigation water that should be applied for optimum growing conditions during each period of low soil moisture. The second factor, economics, will determine what tobacco acreage will be planted. The Ontario Flue-Cured Tobacco Growers' Marketing Board sets compulsory maximum limits on the basis of a percentage of the basic marketing acreage (see section on Land Use) after assessing the economic conditions in the flue-cured tobacco industry.

To assess the variability of the effect of climate on annual irrigation water requirements, a study was made of the long-term records of applied irrigation water made available by staff of the Delhi Research Station. The data show the inches of water applied on tobacco each year at the station during the period 1956-1968. A cumulative frequency curve showing the amount of irrigation water applied on the tobacco crop at the station for the period is presented in Figure 54. The amounts of water applied annually during this 13-year period, ranged from 0.90 to 5.83 inches of water. The median value, 2.93 inches, was applied in 1964.

The ranges of the water requirements in the basin under different sets of seasonal soil moisture deficiencies is of interest, as it indicates the approximate demands the irrigators as a group will place on the water resources in the basin during the summer season. To this end Table 33 was prepared. It shows the estimated water requirements of the total basin for the irrigation of tobacco crops during the summer season for selected tobacco acreage and soil moisture deficiencies at selected annual recurrence intervals. It is based on the water applied on the tobacco crops at the Delhi Research Station during 1956 to

Table 33. **Estimated Annual Irrigation Requirements in Millions of Gallons for Selected Tobacco Acreages and Soil-Moisture Deficiencies during Irrigation Periods at Selected Recurrence Intervals**

Average Recurrence Interval of Soil-Moisture Deficiency	Annual Water Requirements in Million Gallons for Selected Tobacco Acreages Planted expressed as Percentages of Basic Marketing Acreage (BMA)			
	48.3% (1964)	73.5% (11-year mean)	84.0% (1967)*	100% (BMA = 36,400)
10-year high	>1200	>1800	>2000	>2400
5-year high	> 940	>1400	>1600	>1900
2-year**	630	960	1100	1300
5-year low	< 390	< 590	< 690	< 810
10-year low	< 310	< 470	< 540	< 640

* The highest Basic Marketing Acreage planted occurred in 1967.
** The 2-year values represent 1964 soil-moisture deficiencies.
>= larger than
<= smaller than

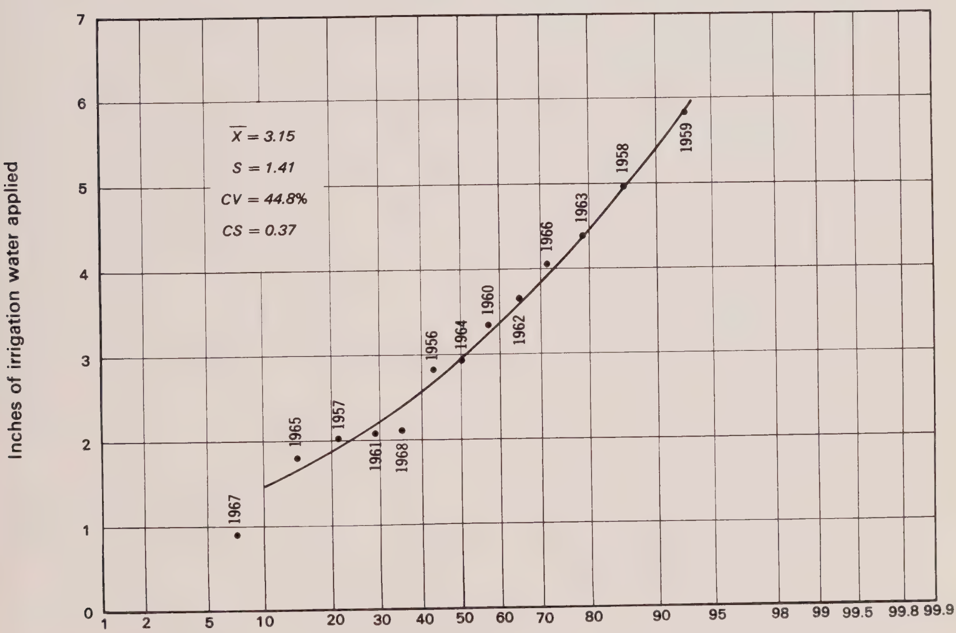


Figure 54. **Cumulative frequency curve of irrigation water applied on tobacco crop at Delhi Research Station, Big Creek basin.**

1968, the estimated amount of water applied on the tobacco crops throughout the basin in 1964 and the following two assumptions:

(1) The ratio between the estimated inches of water applied on the total tobacco acreage in the basin and that applied at the Delhi Research Station in 1964 would hold for the period 1956 to 1968.

(2) That the irrigative water requirements in 1964 were satisfied as far as the average tobacco farmer was concerned.

It is of interest to note that if the largest tobacco acreage planted since 1958 had occurred in 1964 rather than in 1967, the estimated water requirements for the basin in 1964 would have been 1100 million gallons rather than 630 million gallons, and if met, would have depleted streamflow further and caused increased interference with the other uses in the streams.

From Figure 54 and the above assessment, it would appear that the water requirements in the basin were at their greatest peak during the 1959 summer season. An approximate estimate of that year's requirements is about 2,000 million gallons, which if taken, would have created extremely-low streamflow conditions in the Big Creek basin. Streamflows at the gauging station on Big Creek near Delhi in 1959 were the lowest on record for the 7-, 15- and 30-day periods (Table 13).

During 1964, irrigation of tobacco crops occurred from June 12 until August 5, and was practised daily from June 30 to August 5 in the basin above the Delhi streamflow gauging station. In Figure 55, histograms show the number of irrigators who reported taking water and the total reported daily water taken during the 1964 summer season in this sub-basin. From this figure it is apparent that July was a month of low soil-moisture conditions. The period July 20 to July 31 had especially high irrigative water demands.

The reported daily takings, the percentage of farmers irrigating and the estimated total daily takings during the period July 20 to July 31 in areas above the Delhi gauge are shown in Table 34. The table indicates that the percentage of irrigators irrigating on the same day varied greatly in the three sub-basins. This suggests that soil-moisture conditions may have differed from area to area. The availability of water may, however, be a determining factor. The proportion of farmers irrigating in the basin over various consecutive-day periods is illustrated in Figure 56 for the sub-basin above the Delhi streamflow gauging station.

The estimated maximum day and maximum seven-day water takings in the Big Creek basin in 1964 are estimated to be about 38 and 30 mgd, respectively. The former amounts to about 6 per cent and the latter to about 30 per cent of the total water taken for tobacco irrigation.

Recreational and Wildlife Uses

General recreational use of water is made at the reservoirs at the Lehman Dam and the more-recently constructed dam on Deer Creek where areas have been set aside specifically for this purpose. Other areas are also available and recreational use of water in the form of swimming and picnicking is made at other locales as well. Boating and canoeing are other uses, especially in the lower reaches of Big Creek. Big Creek and its tributaries are well known for trout fishing. Because of the favourable conditions, rainbow trout use the streams extensively as spawning grounds. The extensive marshy areas at the mouth of Big Creek are nesting grounds for numerous water fowl.

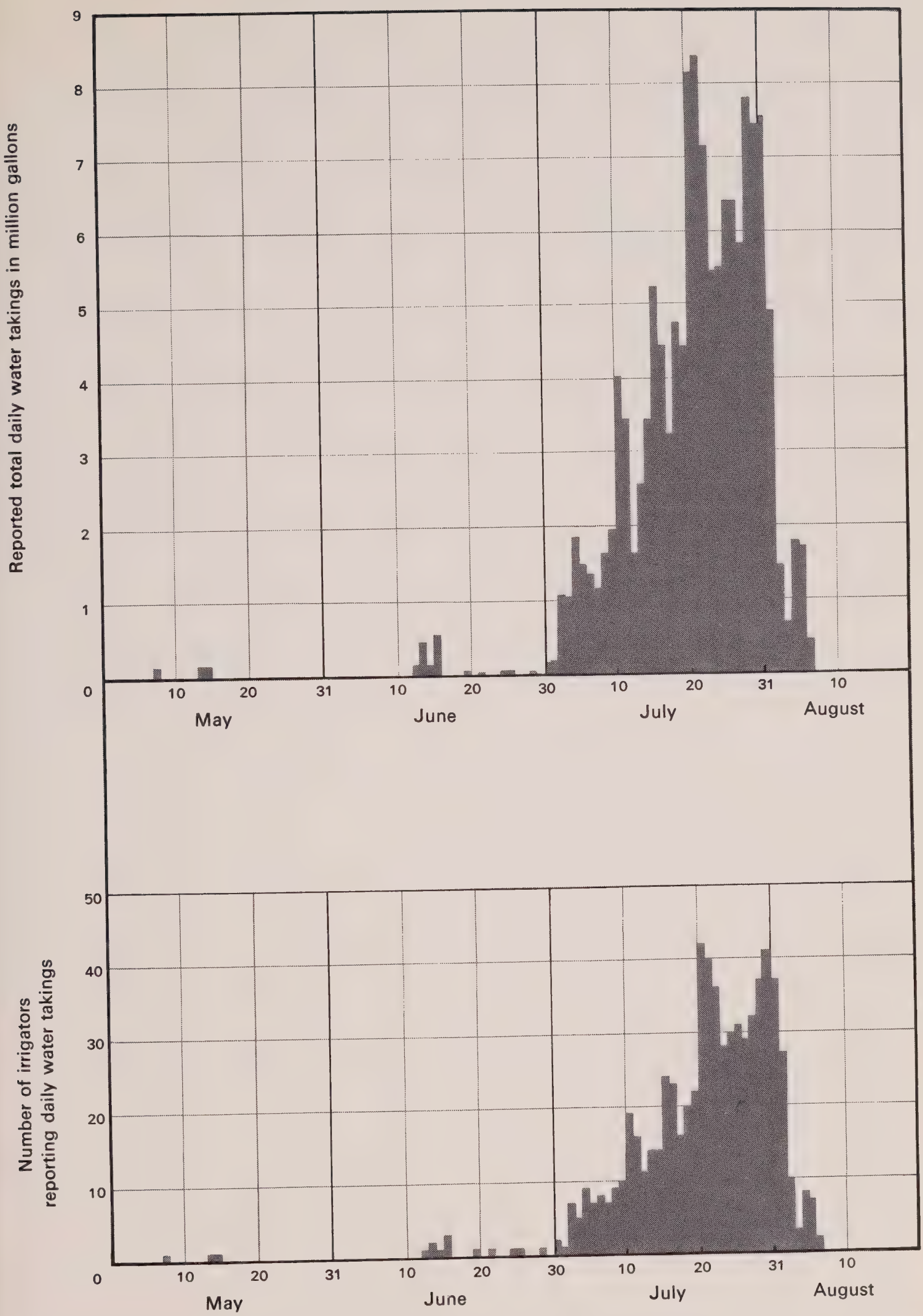


Figure 55. **Reported number of irrigators and the total daily taking of water, Big Creek basin above the Delhi streamflow gauging station, 1964.**

Table 34. Reported Daily Water Takings for Irrigation, Percentage of Irrigators Irrigating and Estimated Total Water Taking for Irrigation, Big Creek Basin above Delhi, during Maximum Water Use Period July 20 to July 31, 1964

Date	Big Creek Basin above Kelvin Streamflow Gauging Station			North Creek Basin above Delhi			Big Creek Basin above Delhi Streamflow Gauging Station		
	Reported Takings (mgd)	Per cent of Irrigators Irrigating	Estimated Total Takings (mgd)	Reported Takings (mgd)	Per cent of Irrigators Irrigating	Estimated Total Takings (mgd)	Reported Takings (mgd)	Per cent of Irrigators Irrigating	Estimated Total Takings (mgd)
July 20	1.06	17.9	2.2	0.94	16.3	1.9	8.16	21.6	16.8
21	0.97	17.9	2.0	1.75	23.3	3.5	8.38	20.6	17.3
22	0.95	15.4	2.0	1.41	18.6	2.8	7.17	18.5	14.8
23	0.52	7.7	1.1	1.15	14.0	2.3	5.45	14.4	11.2
24	0.83	10.2	1.7	1.21	14.0	2.4	5.50	14.9	11.3
25	0.62	5.1	1.3	1.57	18.6	3.2	6.42	16.0	13.2
26	0.62	7.7	1.3	2.05	25.6	4.1	6.40	14.9	13.1
27	0.35	7.7	0.7	1.98	25.6	4.0	5.81	16.5	12.0
28	0.79	10.2	1.6	1.94	21.0	3.9	7.80	19.1	16.1
29	0.72	7.7	1.5	1.77	23.3	3.6	7.43	21.1	15.3
30	0.66	10.2	1.4	1.30	16.3	2.6	7.56	19.6	15.6
31	0.09	5.1	0.2	0.93	11.6	1.9	4.91	14.4	10.1

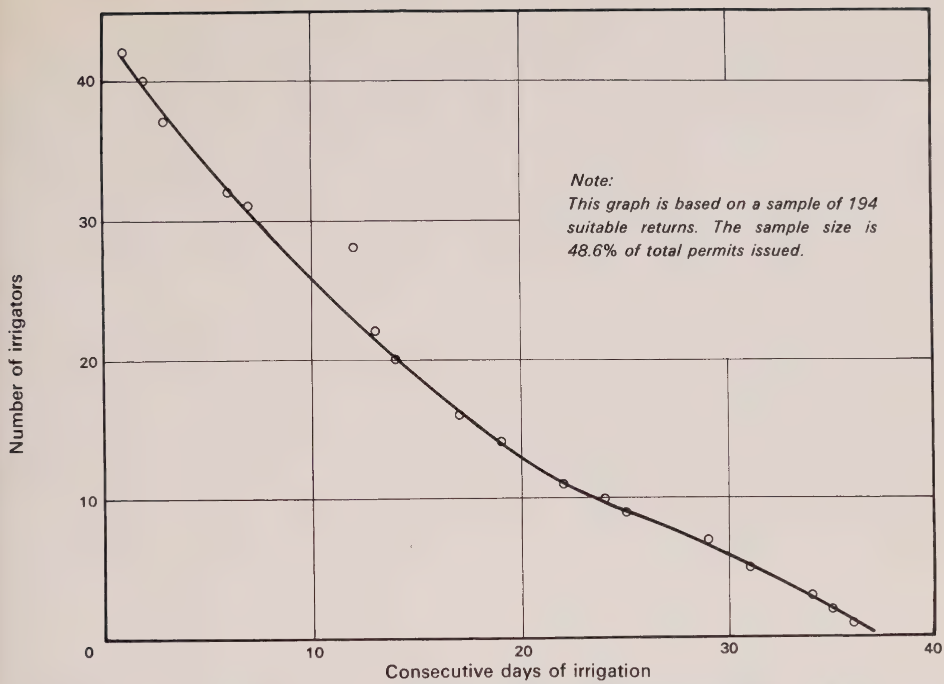


Figure 56. Duration of irrigation by individual irrigators, Big Creek basin above the Delhi streamflow gauging station, 1964.

Waste Disposal

The disposal of wastes has not been a serious problem in the basin. The only significant source of sewage effluent that is discharged into Big Creek is the Town of Delhi's municipal water pollution control plant. Some sewage is possibly discharged to Big Creek directly through illegal connection to the storm drainage system in the Town of Delhi. (Ontario Water Resources Commission, 1963). Other domestic sewage in the basin is disposed of through septic tanks and tile fields.

The existing municipal water pollution control plant of the Town of Delhi is a high-rate trickling filter plant. Inspections by the OWRC have shown that the plant is frequently not producing a satisfactory effluent while operating at only two thirds of its design loading. It is estimated that in 1964 about 0.35 mgd of plant effluent was discharged into Big Creek. Actual records collected at this plant give substantially lower values but were not considered to be reliable, owing to difficulties with the metering system.

The waste loadings imposed on Big Creek by this plant's effluents and by the discharges of sulphurous waters from two abandoned flowing gas wells in and near the Town of Delhi have resulted in the assimilation capacity of Big Creek being exceeded during periods of low flow. The water quality of Big Creek below Delhi during low flow periods can be improved by continuing modifications to the municipal treatment plant and by plugging of the abandoned flowing wells.

Table 35. Estimated Water Use by Major Purpose for Selected Time Periods in 1964, Big Creek Basin

(Water use expressed in million gallons, MG, and in per cent of total water use for selected time period, %)

Type of Use	Annual		55 days		37 days		30 days		15 days		7 days		3 days		1 day	
	MG	%	MG	%	MG	%	MG	%	MG	%	MG	%	MG	%	MG	%
Irrigation	630	59	630	90	620	92	600	94	430	96	220	96	110	96	38	97
Livestock	82	7.7	12	1.7	8.3	1.2	6.7	1.0	3.4	0.7	1.6	0.7	0.7	0.6	0.2	0.5
Municipal	140*	13	30	4.3	21	3.1	18	2.8	8.8	1.9	4.1	1.8	1.8	1.6	0.6	1.5
Rural Domestic	220	21	33	4.7	22	33	18	2.8	9.1	2.0	4.2	1.8	1.8	1.6	0.6	1.5
Total Use	1070		700		670		640		450		230		110		39	

* Municipal water use based on monthly records.

Irrigation was practised daily during the 3-, 7-, 15-, 30-, and 37-day periods.
The 55-day period contains the first and last day of the 1964 irrigation periods.

The natural low flows in Big Creek are reduced substantially by large water withdrawals for irrigation during the summer period. During 1964, the lowest recorded mean daily streamflow at the gauge at Delhi was 11.7 cfs, which is estimated to be about 27 per cent of the natural flow. The lowest instantaneous flow reported is 7.1 cfs which occurred in 1965 and 1966 during the prime-irrigation period. There is, therefore, in the basin a serious conflict between seasonal consumptive water use by upstream irrigators and the waste assimilation and dilution requirements imposed by the effluents from Delhi's water pollution control plant.

Summary of Uses

A summary of the estimated amounts of water used in the basin in 1964 is presented in Table 35. The total estimated water withdrawals are shown by use and expressed in mgd and per cent of total water used for a number of selected periods in 1964. The values shown are the largest ones that occurred during the selected time periods except for the annual value. The 37-day period was selected as it represented the period June 30 to August 5 during which time irrigation was practised daily in the basin. The preponderance of the irrigative water use in comparison to the other uses is noticeable and ranges from 97 per cent for the maximum day to 90 per cent of the 55-day period of irrigation.

Of the three broad types of water uses in 1964 (irrigation, rural domestic and livestock, and municipal), the irrigative water use comprised 59 per cent (630 million gallons), rural domestic and livestock 28 per cent (300 million gallons), and municipal water use 13 per cent (140 million gallons) of the total water use in the basin. The municipal water use is concentrated at the Town of Delhi. Irrigation is practised throughout the whole basin with the exception of the northerly and southerly clay areas which occupy only 20 per cent of the basin area. Rural domestic and livestock water use is distributed throughout the basin with heavier concentrations in livestock in the clay areas.

Correlation Between Irrigation Water Use and Reduction in Streamflow

During the summer season extensive withdrawals of water are made from ground- and surface-water sources in the Big Creek basin. The net effect of the withdrawals is a significant reduction in streamflow. Because most of the water was used for irrigation a correlation should exist between the amount of streamflow reduction and the amount of irrigative water use.

The establishment of such a correlation would be useful in determining natural streamflow conditions during the irrigative season; this would be an essential base for any water-management program. The data would also serve as a means of checking the estimates of base flow made elsewhere in this report.

Correlative work was restricted to data for the 1964 summer season. Detailed analyses were made for the basin above the Delhi streamflow gauge on Big Creek. Limited analysis was made for the drainage areas above the Walsingham gauges on Big Creek and Venison Creek.

The reported and total estimated water takings in the drainage area above the Delhi streamflow station during selected consecutive-day periods of maximum water withdrawals are presented in Table 36. Natural flows, computed on the basis of base flows shown in figures 21 and 22 and the estimated streamflow reductions at the station during these periods are also shown.

Table 36. **Reported and Estimated Irrigation Water Takings, Big Creek Basin above Delhi, during Periods of Maximum Consecutive-Day Water Withdrawals within the 1964 Prime-Irrigation Period, and Estimated Streamflow Depletion in Big Creek at the Delhi Streamflow Station during these Periods**

Periods of Maximum Consecutive-Day Water Withdrawals		Irrigation Water Takings (mgd)				Estimated Depletion in Streamflow during Each Period		Estimated Natural Flow
		Reported*		Estimated				
Consecutive-Day Period	Day(s) of Occurrence	All Sources	Surface Water	All Sources	Surface Water	mgd	%	mgd
1-day	July 21	8.4	4.2	17.3	6.8	4.2	17	24.1
2-day	July 20-21	8.3	3.8	17.0	6.3	2.1	8.3	25.2
3-day	July 20-22	7.9	3.4	16.3	5.6	3.1	12	24.8
4-day	July 20-23	7.3	3.1	15.0	5.1	3.6	15	24.5
5-day	July 20-24	7.0	3.0	14.4	4.9	4.5	18	24.3
7-day	July 20-26	6.8	3.1	14.0	5.1	7.4	31	24.1
10-day	July 20-29	6.8	3.0	14.1	5.0	9.4	39	23.9
15-day	July 17-31	6.2	2.7	12.8	4.5	8.2	33	24.6
30-day	July 2-31	4.3	1.7	9.0	2.9	4.1	15	26.8
37-day	June 30-Aug 5	3.7	1.5	7.6	2.5	4.3	15	28.3

*The water takings as reported are based on records submitted by 48.6 per cent of the permittees.

The total estimated water takings in Table 36 are based on the assumption that the pattern of water use presented by water-taking records was applicable to the entire drainage area.

The reduction in the streamflow of Big Creek near Delhi during the 7-day period of highest water withdrawal was estimated to be 53 per cent of the total water takings during the period. The total estimated surface-water takings were only 69 per cent of the estimated reduction in flow indicating that ground-water takings affected the streamflow as well. Similar conclusions can be drawn for the 10-, 15,- 30- and 37-day periods.

The data as presented in Table 36 suggest that a time lag of at least one day exists between the surface-water takings and the resulting reduction in flow at the Delhi streamflow station and that a much larger time lag exists between the ground-water takings and the resulting streamflow depletion at Delhi. The most severe effects of water takings on streamflow depletion in Big Creek near Delhi are presented in Table 37 for the selected multiple-day periods. Reductions in natural flow of some 73 per cent for the one-day and 63 per cent for the seven-day maximum depletion period indicate the severity of the effects of water takings on basin discharge.

Table 37. Estimated Streamflow Depletion in Big Creek at the Delhi Streamflow Station during Selected Periods within the 1964 Prime-Irrigation Period when this Depletion was most Severe

Periods of Maximum Consecutive-Day Streamflow Depletion		Streamflow Big Creek near Delhi (mgd)		Estimated Depletion in Streamflow during each Period	
Consecutive-Day Period	Date(s) of Occurrence	Estimated Natural Flows	Reported Flows	mgd	%
1-day	Aug 1	23.3	6.3	17.0	73
2-day	Jul 31-Aug 1	23.3	6.8	16.5	71
3-day	Jul 30-Aug 1	23.4	7.4	16.0	68
4-day	Jul 29-Aug 1	23.4	7.8	15.6	67
5-day	Jul 28-Aug 1	23.4	8.0	15.4	66
7-day	Jul 26-Aug 1	23.5	8.8	14.7	63
10-day	Jul 24-Aug 2	23.6	10.3	13.3	56
15-day	Jul 19-Aug 2	23.9	14.0	9.9	41
30-day	Jul 4-Aug 2	26.6	21.6	5.0	19
37-day	Jun 30-Aug 5	28.3	24.0	4.3	15

There is good agreement between the streamflow depletion values and the estimated total water takings as to magnitude for the 1- to 10-consecutive-day periods, but the times of occurrence between these periods differ greatly. Much poorer correlation exists between similar values for the 15- to 37-day periods due to several days of heavy rains whose effects mask the total streamflow depletion that occurred due to irrigation water takings.

Comparisons between the estimated total takings and estimated streamflow depletion values for the 1- to 10-consecutive day periods are presented in Table 38. The estimated streamflow depletion values as shown are not necessarily the result of the specific estimated water-use values shown, but represent the accumulated effects of prior and concurrent water takings in the basin above Delhi; however, there are remarkable similarities between these

values. The time in days or lag-time between the midpoints of each selected period of maximum water withdrawal and maximum streamflow depletion varies from 11 days for the one-day period to 4 days for the 10-day period.

Table 38. **Comparison of Estimated Total Water Withdrawals for Irrigation and Estimated Streamflow Depletion during Selected Periods, Big Creek Basin above Delhi, 1964**

Consecutive-Day Period	Estimated Maximum Water Withdrawal (mgd)	Estimated Maximum Streamflow Depletion (mgd)	Ratio of Streamflow Depletion to Water Withdrawal	Lag Time between Midpoints of Maximum Water-Withdrawal and Maximum Streamflow-Depletion Periods (days)
1-day	17.3	17.0	0.98	11
2-day	17.0	16.5	0.97	11
3-day	16.3	16.0	0.98	10
4-day	15.0	15.6	1.04	9
5-day	14.4	15.4	1.07	8
7-day	14.0	14.7	1.05	6
10-day	14.1	13.3	0.94	4

The consecutive-day periods for the maximum water takings and for the maximum streamflow depletion do not coincide. See Tables 36 and 37 for dates of occurrence.

The estimated effects of water withdrawals for irrigation on streamflow in Big Creek and Venison Creek at the gauging stations near Walsingham during the summer of 1964 are summarized below:

Location	Period of Maximum Streamflow Depletion		Streamflow (mgd)		Estimated Depletion in Streamflow	
	Consecutive-Day Period	Date of Occurrence	Estimated Natural Flow	Reported Flow	mgd	%
Big Creek near Walsingham	1-day	Aug 1	45.2	21.7	23.5	52
	3-day	Jul 30-Aug 1	45.4	22.0	23.3	51
	7-day	Jul 26-Aug 1	45.7	23.4	22.4	49
Venison Cr. near Walsingham	1-day	Jul 31	10.1	7.1	3.0	30
	3-day	Jul 30-Aug 1	10.1	7.3	2.8	28
	7-day	Jul 26-Aug 1	10.2	6.7	2.1	21

Water Resource Development

Surface Water

Existing Development

To provide additional water to that normally available in the streams, especially during low-flow periods, dams have been built on many of the tributaries of Big Creek and also on Big Creek itself. In the basin, two main types of dams exist: (1) small earth dams, on tributary streams that store

small volumes of water for irrigation purposes; and (2) large concrete or earth dams that pond water for water supply, recreation and milling purposes. The dams in operation or in existence in the basin in 1964 are shown on Map 2706-7. Included are the mill dams at Teeterville and Delhi. Since 1964, two dams and reservoirs were constructed by the Big Creek Region Conservation Authority, namely the Lehman and Deer Creek dams.

The Lehman Dam, completed in 1965, was built on North Creek to provide a surface-water supply for the Town of Delhi. The dam created a reservoir of about 120 acre-feet at normal water level of which approximately 100-acre-feet would be available for water supply. This dam is owned by the Big Creek Region Conservation Authority but day-to-day operations are handled by the Public Utilities Commission of the Town of Delhi.

The Deer Creek Dam, completed in July 1969, provides a reservoir with 1,485 acre-feet of storage which is used for irrigation water and recreation. The reservoir created by this dam is 1.5 miles long with about 15 "fingers" extending from the main body of water. It has been stocked with trout. Norfolk County Road 4 crosses the top of the dam.

Recommended Development

In the Water Section of the Big Creek Region Conservation Report, 1958, three dam and reservoir sites were recommended for further consideration from a total of 11 sites investigated. Table 39 lists these three recommended sites and also the eight additional sites which were investigated by the Conservation Authorities Branch, currently with the Department of Energy and Resources Management. Their locations are shown, except for the ones recommended on North Creek, on Map 2706-7.

The Delhi reservoir recommended for construction on Big Creek, if managed and operated to augment the flow in Big Creek, would improve low flow conditions, especially during the period when the effects of irrigation on streamflow are most severe. The increased streamflow would also improve the capacity of the stream for assimilation and dilution of the effluent from the Delhi water pollution control plant and that discharged from the abandoned flowing gas wells. Better assimilation of waste should result in higher dissolved oxygen levels in Big Creek providing an improved habitat for the brook and rainbow trout which are stocked on a regular yearly basis by the Department of Lands and Forests and for the larger trout which enter the stream from Lake Erie during various times of the year.

The table below indicates the approximate increase in flow that could be generated in Big Creek at the dam site in addition to the normal flow if this reservoir were built and operated as suggested.

Consecutive Day Period	Mean Discharge from Reservoir in Addition to Inflow (cfs)
30-day	23
40-day	17
50-day	14
60-day	11

Table 39. **Reservoir Data for Recommended and Investigated Sites, Big Creek Basin**

	Name of Reservoir	Tributary Drainage Area (square miles)	Reservoir Data			
			Length (miles)	Average Width (feet)	Surface Area at Maximum Water Level (acres)	Storage Capacity at Maximum Water Level (acre-feet)
Sites Recommended for Further Consideration	North Creek – Scheme A	12.7	2.2	400	160	2,100
	– Scheme B (Upper Site)	10.1	0.8	350	50	280
	– Scheme B (Lower Site)	12.7	1.5	400	54	596
	Delhi	116.2	2.5	460	182	1,400
Sites Investigated	Oriel	3.6	0.6	875	77	260
	New Durham	22.4	0.8	2,650	58	100
	La Salette	96.8	1.8	680	174	3,260
	Glenshee	6.1	1.6	290	77	610
	Wyecombe	4.8	1.4	1,050	154	2,240
	Langton	17.6	2.3	425	115	1,200
	Marston	24.2	2.0	635	192	3,280
	Venison	33.5	1.6	3.5	96	800

Data extracted from Water Section, Big Creek Region Conservation Report, 1958.

The estimated observed natural low flows in Big Creek near Delhi for a 20-year return period are presented below:

Consecutive Day Period	Mean Discharge without proposed Delhi Reservoir (cfs)
7-day	11
15-day	19
30-day	23

The above tables indicate that an improvement of at least double the estimated seven-day average could be realized even with a 60-day reservoir discharge period and consistent discharge. More intensive manipulation of discharges from the reservoir could increase the seven-day low flow even further and provide water to meet the needs of increased population or use.

Ground Water

Existing Development

The occurrence and availability of ground water are dependent on the existence of a favourable geologic unit or aquifer. Sands and gravels are excellent aquifers and because of their wide-spread distribution in the Big Creek basin, provide an economic source of water in most areas, especially where surface sources are unavailable. The bedrock is also a ready source of ground water but to a lesser extent because of less desirable quality characteristics.

Because of its availability, ground water can readily be developed by means of wells and is the prime source of water for rural-domestic and stock purposes. Because of its shallow occurrence on the sand plain it is also an important source of water for irrigation. In areas remote from streams, dugout ponds penetrate the ground-water reservoir and provide an economic source of water for this purpose.

The table below lists statistics on wells drilled in the basin from 1947 up to the end of 1964:

Source of Water	Number of Wells	Number of Wells Abandoned	Number of Wells Used for Irrigation
Overburden	511	38 (insufficient supply)	25 (well-point system)
Bedrock	121	12 (sulphurous quality)	7
Total	632	50	32

The table shows a high rate of success in the drilling of wells and in the obtaining of satisfactory supplies of water. Even the 38 wells that were abandoned because of insufficient supplies probably encountered water. Failure to develop a supply was probably due more to construction difficulties (fine sand) rather than a lack of water.

The general adequacy of wells in the basin was investigated statistically through a sampling of 814 wells of various types (dug, driven, and drilled), located in various parts of the basin.

Dug and drilled wells are common in the clay and till areas, with dug wells being slightly more common. The adequacy of the wells is significant in that about 40 per cent of the dug wells were adequate while 93 per cent of the drilled wells were adequate.

In the sandy areas driven (sand points) and drilled wells are common with drilled wells predominating at a rate of about three to one. The adequacy of either type of well is high and in the order of 92 to 97 per cent. The adequacy of dug wells in these areas is about 55 per cent and higher than in clayey areas. Construction difficulties probably account for the lower adequacy.

In the total basin, about 67 per cent of the wells were adequate in clayey areas and about 88 per cent of the wells were adequate in sandy areas.

Details are unavailable on the number of dugout ponds in use but their use is significant judging from their common occurrence along roadways in the basin. The extensive use of dugout ponds for irrigation is also evident in Map 2706-6.

Future Development

In 1964, at least 50 per cent of the total water used probably came from ground-water sources, with the main uses being irrigation and rural-domestic supply. Rural-domestic supplies were extracted mainly through wells while irrigation supplies were extracted mainly by means of dugout ponds.

Water withdrawals during the period had profound effects on streamflow, but the main cause was direct withdrawals from surface-water sources. Because of the minimal effects on streamflow due to the withdrawal of ground water, further withdrawals could be made from this source without creating a severe depletion in streamflow. Hydrogeologic conditions are generally suitable throughout the basin for increased withdrawals, either through wells or through dugout ponds.

SUMMARY AND CONCLUSIONS

The primary purpose of this report is to present an evaluation of the surface-water and ground-water resources of the Big Creek basin in terms of quantity, quality, occurrence, and use, with the view to providing a basis for water management in the area.

The Big Creek basin is an extensively-developed agricultural area of 280 square miles, devoted primarily to the growing of tobacco. About 70 per cent of the basin surface is covered with sandy soil, which is highly suitable for tobacco-growing purposes. Long, frost-free periods and a generally adequate annual precipitation add to the favourable growing conditions. Although precipitation is fairly evenly distributed throughout the year, periods of deficiency do occur during the growing season, and intensive supplemental irrigation is practised to overcome the soil-moisture deficiencies as well as to increase crop yields. The resulting competition for water was a factor for undertaking a water-resources survey of this basin.

The bedrock in the basin consists of Silurian and Devonian limestones and dolomites that dip gently in a southwesterly direction. The bedrock surface is relatively flat and slopes from an elevation of about 825 feet above sea level in the north to an elevation of about 300 feet in the south.

The overburden in the basin varies in thickness from about 25 feet in the north to about 325 feet in the south. Much of the overburden consists of beds of clays, silts and fine sands of lacustrine origin. Tills of glacial origin are common on the morainic ridges as are kame and outwash sands and gravels of glacio-fluvial origin. The basin is characterized by broad, flat, sand plains where surficial sand deposits of lacustrine and glacio-fluvial origin average 20 to 30 feet in thickness.

The long-term mean annual precipitation at Delhi is 37.02 inches and is representative of basin conditions. The monthly precipitation is, as a rule, fairly evenly distributed but wide variations are common.

Big Creek and its two main tributaries — North Creek and Venison Creek — drain an area of approximately 280 square miles. Controlled in part by the morainic ridges, the streams have dissected deep valleys into the flat sand plain. Near the deep valleys, drainage is generally good, but improvements in the drainage has been necessary in some more remote areas where bogs and swamps exist.

High flows in the streams occur during the spring snow-melt period but flows of similar magnitude can occur during the summer season as the result of storms. The maximum mean daily flows recorded in Big Creek at Delhi and Walsingham were 4,910 and 3,060 cubic feet per second, respectively, and have an estimated recurrence interval of 14 years. The maximum flow recorded in North Creek was about 1,000 cfs with a recurrence interval of 11 years. The highest recorded flow in Venison Creek is 1,580 cfs.

Low flows occur in the streams during the summer and fall seasons, a time when heavy withdrawal demands are placed on the water. The minimum mean daily flows recorded in Big Creek at Delhi and Walsingham were 6 and 33 cfs, respectively, and occurred during periods of heavy water withdrawal for irrigation. The minimum seven-day flow recorded at Delhi and Walsingham

during the irrigation period was approximately 16 and 36 cfs, respectively. Under natural conditions, the seven-day flow would have been about 30 and 60 cfs, respectively. Even under natural conditions, low flows in North Creek can approach zero. The minimum daily flow recorded on Venison Creek was 8 cfs and occurred during heavy withdrawal periods.

Flow-duration curves indicate that 50 per cent of the time the mean daily flow in Big Creek at Delhi and Walsingham exceeded 72 and 150 cfs, respectively. In 1964, streamflow amounted to approximately 15.2 inches or 40 per cent of the annual precipitation.

Ground water occurs in abundance in the surface sand deposits which cover much of the basin. Ground water also occurs in sands and gravels along the morainic ridges, and within the upper part of the bedrock. Ground water is a good source of supply in most areas of the basin. In the extreme southern part of the basin, supplies are meager or of unsuitable quality and the resource is inadequate for most purposes.

In the surface sand, the water table is usually at shallow depth and water supplies can be obtained readily by means of dug wells, well points and dugout ponds. Where the surface sand is inadequate, water supplies can generally be obtained by means of wells drilled deeper into the overburden and the bedrock. Yields from single wells can generally be expected to be less than 50 gallons per minute in much of the basin. Although ground water is abundant in saturated sands in the basin, individual extractions are limited to low yields because of grain size and permeability. Larger yields from single wells are possible in limited areas.

Most ground water in the basin moves toward and discharges into Big Creek and its tributaries. The water-table fluctuations average about four feet in the surface sand and generally rise from December to April and then decline. Ground-water discharge or runoff in 1964 averaged about 0.28 million gallons per day per square mile but varied from 0.17 to 0.51 mgd per square mile during the year. In 1964, ground-water discharge amounted to approximately 7 inches, or 18 per cent of the total annual precipitation. Ground-water discharge is significant in the basin and maintains stable flows in the streams during low-flow periods.

The mean annual potential evapotranspiration of water in the basin is computed to be 24 inches over a five-year period. The evapotranspirational losses of water in the basin, calculated on the basis of the difference between precipitation and runoff, is approximately 23 inches per year, and amounts to approximately 70 per cent of the total precipitation for the period.

An annual hydrologic budget for the basin for the period July 1, 1964, to June 30, 1965, is as follows:

Precipitation		Total Runoff		Evapotranspiration
37.9 inches	=	15.2 inches	+	22.7 inches

where

Total Runoff		Direct Surface Runoff		Ground Water Runoff
15.2 inches	=	8.2 inches	+	7.0 inches

This budget is considered to be representative of near normal hydrologic conditions.

Waters from most surface-water and ground-water sources are of the calcium-magnesium bicarbonate type, and in terms of chemical quality, all of these waters are suitable for most purposes, particularly domestic, stock and irrigation uses. There was no evidence to indicate any gross chemical pollution. The bacteriological quality should be determined on an individual basis for all waters used for drinking purposes.

Ground water from deep bedrock horizons appears to be of the calcium-magnesium sulphate type. These waters can be hazardous if used for irrigation and their quality should be examined closely before being used for this purpose.

Surface water and ground water show similar chemical characteristics, particularly during base-flow conditions. This reflects the hydrologic relationship between the two waters.

The total use of water in the basin in 1964 for all purposes and from all sources was estimated to be 1,070 million gallons. Of this total, about 56 per cent was used for irrigation of tobacco during the month of July. The use of water for irrigation averaged about 11 mgd over a 55-day period, but reached a maximum of about 38 mgd on one day. The withdrawal and use of water for all other purposes averaged about 1.2 mgd throughout the year.

The withdrawal of water for irrigation greatly affected the streamflow in the basin. The estimated maximum reductions in flow in Big Creek immediately below Delhi amounted to 73 per cent of the daily flow and 63 per cent of the seven-day flow. Interference with other uses and natural stream functions during these periods is obvious.

A combination of drought during the prime growing season and above-average acreage planted to tobacco could result in even greater demands for water for irrigation in some future years.

Although irrigative use is severe during short periods of time, the quantity used is small in comporison to the annual supply of water. With more intensive management, beneficial uses of the local water resources could be increased and problems of interference greatly reduced. Suitable sites exist in the basin for storage reservoirs which would be one means of improving the availability of water throughout the periods of heavy water demands. Greater use of ground-water resources would be another means of alleviating the severity of reduction in streamflow.

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APPENDIX A

Records of Selected Water Wells in the Big Creek Drainage Basin

Only those wells of which direct mention is made in the report appear in this appendix. Logs for all other wells, shown on Map 2706-1, are on file with the Division of Water Resources, OWRC.

Abbreviations Used

A — abandoned
Bk — black
Bl — blue
Bld — boulders
Bn — brown
C — commercial
Cem — cemented
Cl — clay
Cly — clayey
Co — county
Con — concession
Cse — coarse
D — domestic
Dk — dark
Dty — dirty
F — fine
Gr — gravel
Gry — gravelly
Gy — grey
Hd — hard
Hp — hardpan
Ind — industrial
Irr — irregular
Ly — layer
Lm — Loam
Ls — limestone
Lse — loose
Med — medium
N — north
P — public
Pbl — pebble
Qsd — quicksand
Rd — red
Rk — rock
S — south, sulfur, stock
Sd — sand
Sdy — sandy
Sf — soft
Sh — shale
Shy — shaly
Slt — silt
Slty — silty
Sm — small
Str — streak(s)
Sts — stones
Sty — stony
T — Test hole
T.R.N. — Talbot Road North
T.R.S. — Talbot Road South
Ts — topsoil
Twp — Township
V — very
Wh — white
Yl — yellow

Appendix A. Records of Selected Water Wells in the Big Creek Drainage Basin

(locations of numbered wells are shown on Map 2706 - 1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Use	Log and Remarks (depths in feet)
	Twp. of East Oxford										
2	Con VI Lot 8	L. Huggins	31/12/62	4	106	29	5	34	Fresh	D	Dug 12; Bl Cl 55; Qsd, Bld 99; Cl, Gr 106. Water at 103.
6	" VIII " 10	H. Andrews	27/ 2/55	4	124	20	9	30	"	D,S	Sd 10; Sts, Cl 42; Bl Cl 73; Hp 119; Sh 124. Water at 124.
8	" VIII " 5	D. Avey	28/ 7/59	3	55	14	4	34	"	D	Yl Cl 15; Hd Gry Cl 54; F Gr 55. Water at 54.
17	" VII " 1	G. Mather	24/ 7/62	5	45	18	3	20	"	D,S	Cl 20; Sd, Gr 40; Hp 42; Gr, Sd 45. Water at 42.
	Twp. of North Norwich										
18	Con I Lot 14	L. Dickson	11/ 9/58	5	29	Flow	-	-	"	D	Bl Cl 27; Gr 29. Water at 27.
30	" I " 7	F. Cohoe	4/ 8/59	4	80	5	5	15	"	D	Sd 25; Bl Cl 50; Hp, Sts 74; Ls 80. Water at 78.
32	" I " 7	J. Lighthart	12/ 7/56	5	61	9	5	15	"	D	Bl Cl 22; Cl, Bld 33; Hp, Bld 60; Gr 61. Water at 61.

34	" I " 2	R. McLellan	13/ 1/61	5	53	12	3	15	"	D,S	Ts 2; Gr, Sd 50; Bn Ls 53. Water at 53.
40	" II " 2	H. Proper	17/ 7/62	5	68	18	4	20	"	D,S	Cl 12; Sd 28; Bl Cl 64; Sd, Gr 68. Water at 64.
	Twp. of Burford										
47	Con VII Lot 18	A. Van Belleghem	30/11/50	6	51	18	10	25	Fresh	D	Till 40; Sty Till 51; Gr 51; Water at 51.
52	" VIII " 10	G. Brown	27/ 6/62	4	60	30	10	31	"	D,S	Sf Yl Sd 12; Sf Putty Sd 25; Hd, Sf Cl Stk 59; Med Gr 60. Water at 59.
63	" IX " 13	A. Hanson	4/ 6/59	4	70	14	5	18	"	D	Hd Cl 12; Sd, Cl 64; Hd Cl 68; Sh 70. Water at 69.
80	" IX " 19	N. Hipfner	28/10/55	4	37	13	2	18	"	D,S	Gy Cl 32; Rk 37. Water at 37.
89	" X " 20	P. Cohoe	24/ 5/61	5	72	20	5	25	"	D, Irr	Ts 1; Rd Cl 5; Bl Cl 56; Sd, Slt, Bld 70; Gr 72. Water at 72.
91	" X " 13	R. Shellington	23/10/59	4	78	55	5	57	"	D,S	F Sd 50; Sdy Cl 75; Hd Cl 77; F Gr 78. Water at 77.
93	" XI " 2	E. Lechowicz	2/11/59	10	60	22	500	40	"	Irr	Sd 23; Cse Sd 40; Sd 60. Water at 43.
96	" XI " 11	M. Podworny	6/ 9/60	2	21	6	10	-	"	D	F Sd 4; Gr 6; Slty Cl 9; Sdy Gr 15; Sd 21. Water at 7.

Appendix A. Records of Selected Water Wells in the Big Creek Drainage Basin

(locations of numbered wells are shown on Map 2706 - 1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Use	Log and Remarks (depths in feet)
	Twp. of Burford (cont.)										
102	" XII " 13	N. Bowman	13/11/53	6	80	21	4	28	"	D,S	Yl Sd 21; Cl, Sts 24; Sd, Cl 49; Bl Cl, Sts 63; Sh 78; Rk 80. Water at 80.
111	" XIV " 1	G. Demeyere	9/ 6/62	5	170	80	10	80	"	D	Sdy Lm 10; Yl Lm 30; Sf Bl Cl 95; Hd Bl Cl 150; Hp 155; Bn Ls 170. Water at 170.
115	" XIII " 1	A. Campbell	28/ 5/60	7	72	51	7	54	"	D	Hd Bn Sd 3; Sd, Cl, Bld 24; Bn Sd, Cl 33; Sd, Slt 45; F Bn Sd 69; F Bn Sd, Slt, Cl 72. Water at 45 to 69.
	Twp. of Windham										
121	Con I Lot 14	H. Treffry	10/ 4/61	5	132	20	12	21	Fresh	D,S	Cl, Sts 30; Sd 40; Qsd 125; Hp 131; Sf Rk 132. Water at 110.
131	" III " 19	A. Jakob	2/11/59	5	40	12	6	22	"	D	Cl 35; Sd 40; Water at 35.
138	" IV " 7	J. Tarcza	10/ 4/62	2	40	20	8	-	"	D	Dug 24; Bn Sd 40. Water at 20.
139	" IV " 6	A. Lundy	4/ 4/62	5	140	24	12	24	"	D	Yl Sd 5; F Sd 20; Qsd 50; Putty Sd 110; Bl Cl 130; Hp Sts 138; Gy Rk 140. Water at 139.

145	" IV " 23	P. McNamara	21/10/60	5	70	30	5	38	"	D	Dug 30; Rd Sd 33; Putty Sd 65; Sd 70. Water at 65.
149	" V " 14	A. Deyne	19/ 6/61	5	120	Flow	20	-	S	D	Yl Sd 30; Sd 38; Gr 40; Cl 120. Water at 120.
150	" V " 13	Twp. School	16/ 6/58	5	30	6	12	10	Fresh	P	Ts 2; F Gr 30; Water at 6.
164	" VIII " 12	Windham Twp.	16/ 8/60	5	40	10	10	20	"	D	Yl Sd 10; Sd, Sts 14; Yl Sd 30; Sd 40. Water at 30.
168	" VII " 10	M. Fakelman	29/ 7/59	7	185	4	250	40	"	Irr	Lm, Gr 25; Bl Cl 90; Qsd 120; Bl Cl 134; Bn Ls 185. Water at 180.
175	" IX " 24	O. Van Den Heede	15/ 4/58	2	32	24	20	28	"	D	Fill 2; Gr, Sd 5; Sd 9; Gr 24; Cse Sd 32. Water at 26.
187	" X " 22	J. Dadurka	9/ 9/59	7	168	55	50	55	"	D	Sd 105; Cl, Sd 140; Cl 158; Bn Ls 168. Water at 167.
189	" XI " 21	E. Clark	27/ 3/62	5	49	22	6	35	"	D	Yl Sd 3; Gr 35; Yl Sd 42; Sd 49. Water at 42.
218	" XII " 19	H. Dunkin	15/ 9/62	5	37	15	5	27	"	D	Ts 1; Sd, Sts 15; Cl, Sd 30; Sd, Gr 37. Water at 30.
234	" XIII " 24	G. Wray	19/11/62	4	53	15	7	20	"	D	F Sd 3; F Gr 25; Bld 29; Cse Sd 53. Water at 46.
261	" XIV " 18	R. Bulloch	16/ 9/59	2	28	21	6	-	"	D	Sd 20; Med Sd 28. Water at 21.

Appendix A. Records of Selected Water Wells in the Big Creek Drainage Basin

(locations of numbered wells are shown on Map 2706 - 1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Use	Log and Remarks (depths in feet)
	Twp. of South Norwich										
269	Gore Lot 34	J. Eber	6/ 4/61	5	133	25	10	33	Fresh	D,S	Sd 10; Cl 30; Putty Sd 80; Cl 100; Putty Sd 110; Cl 130; Wh Ls 133. Water at 130.
275	" " 31	E. DeDobbelaer	4/10/61	5	48	0	5	33	"	D	Cl, Sts 18; Putty Sd 42; F Sd 48. Water at 42.
277	Con XII " 13	C. Demeyere	28/10/59	2	25	12	8	-	"	D	Dug 4; Wh Sd 8; Wh Sd, Sts 12; Cse Gr 18; Med Gr 20; Cse Sd 25. Water at 12.
	Twp. of Middleton										
282	TRN Con I Lot 40	Experimental Farm	27/ 2/61	5	40	16	20	21	Fresh	Irr	Yl Sd 22; Hp 23; Sd 40. Water at 23.
298	TRS Con I Lot 30	P. Lanoo	29/ 9/59	2	18	9	6	-	"	D	Sdy Cl 1; Gr, Cl 5; Sd 8; Cse Ds 18. Water at 9;
301	TRS Con I Lot 31	S. Rupert	14/ 7/61	5	198	60	15	65	S	D,S	Sd 15; Gr 23; Putty Sd 110; Cl 140, Putty Sd 180; Bn Rk 198. Water at 197.

305	TRN Con I Lot 34	D. Waldick	11/ 6/62	2	54	30	8	-	Fresh	D	Ts 3; Yl Sd 9; Bn Sty Cl 21; Sd 30; Bl Qsd 34; Bl Putty Sd 36; Bl Qsd 54. Water at 34.
322	TRN Con I Lot 45	R. Person	23/ 4/64	5	55	31	10	35	"	D,S	Sd 55. Water at 48.
334	TRN Con I Lot 48	G. Kent	15/ 8/62	5	153	35	15	42	S	D	Sd 35; Putty Sd 75; F Sd 95; Cl, Gr, Sd 116; Cl, Cse Gr 120; Bn Ls 153. Water at 150.
345	TRS Con I Lot 39	C. Verschoore	24/ 5/61	2	38	14	5	-	Fresh	D	Ts 2; Cse Sd 14; F Gr 18; Cse Sd 27; F Sd 38. Water at 18.
352	TRS Con I Lot 47	D. White	6/ 4/56	7	220	60	10	60	S	D	Fill 20; Cl, Sd 48; F Sd 80; Sd 130; Cl 150; Cl, Sd 185; Cl 193; Lse Cl 210; Ls 220. Water at 48 and 218.
359	TRS Con I Lot 5	P. Verkuil	2/10/62	5	72	15	5	25	Fresh	D	Yl Sd 4; Yl Cl, Sts 20; Putty Sd 28; Gy Cl, Sts 63; Sd 72. Water at 63.
371	TRS Con III Lot 20	Ont. Dept. Highways	16/ 8/62	5	37	9	20	10	"	D	Ts 5; Rd Sd 10; Cl Lm 15; V F Sd 28; Bk, Wh Sd 37; Water at 15.
375	TRS Con III	P. Schaffer	1/ 7/62	2	30	14	55	-	"	Irr	Ts 1; Sd 22; F Sd 30. Water at 22. (3 wells)

Appendix A. Records of Selected Water Wells in the Big Creek Drainage Basin

(locations of numbered wells are shown on Map 2706 - 1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping Level (feet)	Quality	Use	Log and Remarks (depths in feet)
	Twp. of North Walsingham										
414	Con XIV Lot 6	J. Habl	7/10/58	2	29	14	7	-	Fresh	D	Rd Sd 7; Gy Sd 14; Sd 29. Water at 14.
428	" XIV " 12	C. DeMent	15/10/62	2	34	13	8	-	"	D,S	Dug 12; Gr 17; Bn Qsd 27; Bn Sd 34. Water at 13.
460	" XIII " 24	J. Major	17/10/62	5	72	50	5	61	"	D	Ts 2; Sd 6; Gy Cl 65; F Sd 72. Water at 66.
471	" XII " 24	J. Wiebe	11/ 8/62	8	170	75	40	75	"	D,S	F Sd 140; F Sd, Sts 161; Gy Ls 170. Water at 167.
476	" XII " 6	R. Opdeeam	30/10/61	5	56	34	4	56	"	D	Yl Sd 40; Wh Sd 46; F Sd 56. Water at 46.
494	" XII " 12	P. Hemeryck	25/ 4/60	2	28	20	6	-	"	D	Rd Sd 10; Bn Sd 14; Sd 28. Water at 18.
506	" XII " 18	M. Verstraeten	10/ 5/55	4	14	5	4	7	"	D	Ts 3; Rd Sd 7; Wh Sd 9; Cse Gy Sd 14. Water at 7.

533	" IX " 8	G. Riviere	30/ 8/60	2	30	8	7	-	"	D	Dug 10; Sd 30. Water at 10.
545	" VII " 2	F. Evans	19/ 3/63	1	28	8	8	-	"	D	Bn Sd 28. Water at 24.
559	" VIII " 24	M. Schweitzer	30/ 9/59	2	30	12	3	-	"	D	Ts 4; Dk Sd 10; Wh Sd 17; F Sd to Cse 30. Water at 16.
	Twp. of Charlotteville										
579	Con XI Lot 6	A. Kyle	16/10/62	5	36	26	2	31	Fresh	D	Yl Sd 5; Sd 12; Cl, Sd 20; Sd 36. Water at 30.
595	" IX " 7	N. Horvath	11/ 8/59	1	32	23	8	-	"	D	Dug 4; Yl Sd 23; Gy Qsd 32; Water at 23.
614	" VI " 3	J. Grela	7/11/62	1	25	16	8	16	"	D	F Sd 6; Gy Cl 16; Cse Sd 25. Water at 16.
	Twp. of South Walsingham										
626	Con V Lot 10	S. Rockefeller	25/10/59	1	27	13	6	-	"	D	Ts 13; Slty Sd 21; Med Sd 27. Water at 13.
630	" IV " 13	D. Weber	30/ 3/61	1	26	16	5	-	"	D	Dug 10; F Sd 16; Sd 26. Water at 16.
631	" I " 13	C and M Food Bar	18/ 4/62	1	20	5	1	-	"	D	F Sd 6; Cse Sd 20. Water at 6.

APPENDIX B

Chemical Analyses of Waters in the Big Creek Drainage Basin

Appendix B. Chemical Analyses of Waters in the Big Creek Drainage Basin

(locations of water sampling points are shown on Figure 39)

Source and Number	Location	Date Sampled	pH	Mineral Constituents in parts per million (ppm) (1 ppm = 1 mg/l)										Total Alkalinity as ppm $CaCO_3$	Total Hardness as ppm $CaCO_3$	Total Dissolved Solids in ppm	Specific Conductance micromhos at 25°C	Remarks
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Well 2	E. Oxford Twp. VI - 8	10/ 7/64	7.8	65	18	12	-	0	288	25	2	1.51	0	236	236	-	370	
" 6	E. Oxford Twp. VIII - 10	10/ 7/64	7.7	64	14	11	-	0	283	10	2	1.37	0	232	220	-	370	Rock well
" 8	E. Oxford Twp. VIII - 5	10/ 7/64	8.2	24	12	39	-	0	181	41	3	0.31	0	148	108	-	290	
" 17	E. Oxford Twp. VII - 1	10/ 7/64	7.9	52	20	14	-	0	288	4	3	0.50	0	236	212	-	360	
" 18	N. Norwich Twp. I - 14	10/ 7/64	7.6	98	2	6	-	0	298	21	2	0.80	0	244	252	-	390	
" 30	N. Norwich Twp. I - 7	10/ 7/64	7.7	66	18	8	-	0	290	17	3	1.30	0	238	242	-	390	Rock well
" 32	N. Norwich Twp. I - 7	10/ 7/64	8.2	38	11	48	-	0	242	143	2	0.60	0	198	140	-	410	
" 34	N. Norwich Twp. I - 2	10/ 7/64	7.9	46	19	17	-	0	254	22	6	0.61	0	206	196	-	350	Rock well
" 40	N. Norwich Twp. II - 2	17/ 7/64	7.9	42	18	18	-	0	237	16	1	0.75	0	194	182	-	320	

" 47	Burford Twp. VII - 18	17/ 7/64	7.6	168	25	11	-	0	242	341	8	1.60	0	198	524	-	820	
" 52	Burford Twp. VIII - 10	17/ 7/64	7.7	54	20	9	-	0	274	42	3	1.48	0	224	218	-	350	
" 63	Burford Twp. IX - 13	17/ 7/64	7.8	51	18	14	-	0	252	13	3	2.35	tr	206	204	-	330	Rock well
" 80	Burford Twp. IX - 19	17/ 7/64	7.8	65	16	6	-	0	220	58	4	1.45	0	180	230	-	350	Rock well
" 89	Burford Twp. X - 20	24/ 7/64	7.3	386	100	8	-	0	183	1180	10	5.9	0	150	1380	-	1600	
" 89	"	19/ 2/65	7.4	284	94	26.5	-	0	173	973	13	4.9	tr	142	1100	1658	1500	
" 91	Burford Twp. X - 13	17/ 7/64	7.6	98	23	6	-	0	293	91	15	1.27	tr	240	340	-	520	
" 93	Burford Twp. XI - 2	24/ 7/64	7.7	64	20	3.8	-	0	215	53	6	0.81	2	176	242	-	390	
" 96	Burford Twp. XI - 11	17/ 7/64	7.5	115	18	4	-	0	318	108	13	2.90	tr	260	364	-	530	
" 96	"	3/12/64	-	112	31	5	2.5	0	391	114	-	-	0	320	-	490	620	Silica as SiO_4-9.3
" 102	Burford Twp. XII - 13	17/ 7/64	8.0	32	20	28	-	0	227	20	2	0.70	0.1	186	162	-	320	Rock well
" 111	Burford Twp. XIV - 1	17/ 7/64	8.1	44	16	39	-	0	127	133	1	0.71	0	104	176	-	420	Rock well
" 115	Burford Twp. XIII - 1	17/ 7/64	7.6	70	25	5	-	0	303	50	12	0.18	5.0	248	280	-	530	
" 121	Windham Twp. 1 - 14	17/ 7/64	7.9	35	25	19	-	0	266	7	1	1.0	tr	218	194	-	340	Rock well

Appendix B. Chemical Analyses of Waters in the Big Creek Drainage Basin

(locations of water sampling points are shown on Figure 39)

Source and Number	Location	Date Sampled	pH	Mineral Constituents in parts per million (ppm) (1 ppm = 1 mg/l)										Total Alkalinity as ppm $CaCO_3$	Total Hardness as ppm $CaCO_3$	Total Dissolved Solids in ppm	Specific Conductance micromhos at 25°C	Remarks
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Well 131	Windham Twp. 111 - 19	17/ 7/64	7.4	136	29	11	-	0	403	42	36	0.61	10	330	462	-	780	
" 131	Windham Twp. 111 - 19	19/ 2/65	7.3	101	24	9	-	0	366	41	22	0.29	4.0	300	354	436	590	
" 138	Windham Twp. IV - 7	17/ 7/64	7.9	51	11	3	-	0	156	17	7	0.20	2.6	128	172	-	280	
" 139	Windham Twp. IV - 6	17/ 7/64	8.2	22	12	20	-	0	164	8	2	0.21	0	134	106	-	230	Rock well
" 145	Windham Twp. IV - 23	27/ 7/64	7.7	75	25	5.8	-	0	320	39	2	1.04	0	262	290	-	450	
" 149	Windham Twp. V - 14	17/ 7/64	7.9	50	23	14	-	0	224	56	4	1.47	0	184	222	-	380	
" 149	"	3/12/64	-	40	26	14.5	1.6	0	230	55	-	-	0	188	-	292	375	Silica as SiO_4-11.8
" 150	Windham Twp. V - 13	17/ 7/64	7.7	71	8	3	-	0	217	30	3	1.45	0	178	210	-	330	
" 164	Windham Twp. VIII - 12	30/ 7/64	7.7	82	15	6.5	-	0	249	35	18	0.19	4.4	204	266	-	420	

" 168	Windham Twp. VII - 10	10/ 8/64	8.0	40	17	11	-	0	202	4	3	0.40	tr	166	172	-	300	Rock well
" 175	Windham Twp. IX - 24	27/ 7/64	7.8	78	13	3.1	-	0	198	62	7	0.10	4.0	162	248	-	390	
" 175	"	3/12/64	-	80	26	1.5	21.5	0	237	72	-	-	4.5	194	-	370	480	Silica as SiO_4-8.0
" 187	Windham Twp. X - 22	27/ 7/64	8.1	22	13	33	-	0	193	5	2	0.69	0	158	108	-	250	Rock well
" 189	Windham Twp. XI - 21	27/ 7/64	7.7	78	12	2.7	-	0	205	55	7	0.18	2.5	168	240	-	380	
" 218	Windham Twp. XII - 19	27/ 7/64	7.8	61	15	4.4	-	0	227	32	5	0.69	2.5	186	214	-	340	
" 234	Windham Twp. XIII - 24	27/ 7/64	7.7	80	15	3.8	-	0	259	47	6	0.91	0	212	262	-	410	
" 261	Windham Twp. XIV - 18	27/ 7/64	7.9	66	11	3.7	-	0	146	62	9	0.10	4.0	120	212	-	340	
" 269	S. Norwich Twp. Gore - 34	27/ 7/64	7.9	32	21	14	-	0	220	10	3	0.50	0	180	168	-	280	Rock well
" 275	S. Norwich Twp. Gore - 31	30/ 7/64	7.7	71	25	4.4	-	0	302	12	1	1.21	0	248	254	-	370	
" 277	S. Norwich Twp. XII - 13	27/ 7/64	7.8	74	9	9	-	0	166	67	9	0.14	4.0	136	224	-	370	
" 282	Middleton Twp. TRN I-40	17/ 8/64	7.6	80	16	7.8	-	0	205	64	19	0.31	2.5	168	250	-	430	
" 298	Middleton Twp. TRN I-30	10/ 8/64	7.5	114	16	7	-	0	268	73	17	0.09	7.5	220	350	-	570	
" 301	Middleton Twp. TRS I-31	27/ 7/64	8.0	22	14	43	-	0	205	6	3	0.35	0	168	110	-	260	Rock well

Appendix B. Chemical Analyses of Waters in the Big Creek Drainage Basin

(locations of water sampling points are shown on Figure 39)

Source and Number	Location	Date Sampled	pH	Mineral Constituents in parts per million (ppm) (1 ppm = 1 mg/l)										Total Alkalinity as ppm $CaCO_3$	Total Hardness as ppm $CaCO_3$	Total Dissolved Solids in ppm	Specific Conductance micromhos at 25°C	Remarks
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Well 305	Middleton Twp. TRN I-34	27/ 7/64	7.9	65	14	3.2	-	0	215	41	6	0.81	0	176	220	-	340	
" 322	Middleton Twp. TRN I-45	27/ 7/64	7.9	66	16	5.2	-	0	185	44	24	0.12	1.5	152	230	-	370	
" 334	Middleton Twp. TRN I-48	27/ 7/64	8.1	19	11	35	-	0	178	1	4	0.39	0	146	92	-	250	Rock well
" 345	Middleton Twp. TRS I-39	10/ 8/64	7.9	55	10	1.8	-	0	161	33	5	0.09	2.5	132	180	-	280	
" 352	Middleton Twp. TRS II-47	30/ 7/64	7.6	110	17	42	-	0	266	95	84	0.79	2.4	218	346	-	730	Rock well
" 359	Middleton Twp. TRS I-5	31/ 7/64	7.8	100	27	17	-	0	288	115	28	6.50	tr	236	364	-	515	
" 359	"	19/ 2/65	7.9	55	17	1.5	-	0	200	41	7	0.35	0	164	210	238	320	
" 371	Middleton Twp. TRS III-20	31/ 7/64	8.0	54	11	2.9	-	0	137	71	6	0.29	tr	112	180	-	270	
" 375	Middleton Twp. TRS III-30	10/ 8/64	7.7	86	13	5.5	-	0	207	53	11	0.10	7.0	170	270	-	440	
" 414	N. Walsingham Twp. XIV - 6	31/ 7/64	7.9	54	11	2.7	-	0	166	45	5	0.10	0.5	136	180	-	280	

" 428	N. Walsingham Twp. XIV - 12	31/ 7/64	7.9	54	12	3.6	-	0	161	44	7	0.19	1.2	132	184	-	300	
" 460	N. Walsingham Twp. XIII - 24	30/ 7/64	8.0	38	11	16	-	0	203	9	4	5.80	0	166	142	-	260	
" 471	N. Walsingham Twp. XII - 24	30/ 7/64	7.8	162	23	9.0	-	0	400	163	15	0.90	5.5	328	500	-	550	Rock well
" 476	N. Walsingham Twp. XII - 6	17/ 8/64	7.8	71	10	3.8	-	0	149	54	8	0.20	5	122	220	-	370	
" 494	N. Walsingham Twp. XII - 12	31/ 7/64	8.1	56	9	3.2	-	0	161	39	6	0.09	0.8	132	178	-	280	
" 506	N. Walsingham Twp. XII - 18	31/ 7/64	7.8	72	14	31	-	0	193	56	5	0.10	3	158	238	-	310	
" 533	N. Walsingham Twp. IX - 8	17/ 8/64	7.7	63	9	3.8	-	0	193	70	13	0.25	2.5	158	218	-	430	
" 545	N. Walsingham Twp. VII - 2	17/ 8/64	7.4	66	8	2.9	-	0	190	46	6	0.51	0	156	200	-	340	
" 559	N. Walsingham Twp. VIII - 24	30/ 7/64	8.2	29	7	4.3	-	0	83	45	10	0.16	0.8	68	122	-	210	
" 579	Charlotteville Twp. XI - 6	17/ 8/64	7.7	75	16	4.7	-	0	232	60	6	0.34	0.5	190	254	-	410	

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				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Well 595	Charlotteville Twp. IX - 7	30/ 7/64	7.8	67	9	2.0	-	0	195	23	5	0.19	3.5	160	204	-	330	
" 614	Charlotteville Twp. VI - 3	30/ 7/64	7.7	84	17	8.0	-	0	232	107	8	0.16	0.8	190	280	-	460	
" 626	S. Walsingham Twp. V - 10	17/ 8/64	7.8	76	10	2.8	-	0	173	70	9	0.19	2	142	232	-	380	
" 626	"	3/12/64	7.7	76	24	tr	0.7	0	185	55	17	0.10	1.8	152	290	276	380	Silica as SiO_4 - 8.5
" 630	S. Walsingham Twp. IV - 13	17/ 8/64	7.8	81	8	2.4	-	0	195	49	6	0.25	5	160	234	-	400	
" 631	S. Walsingham Twp. I - 13	17/ 8/64	7.4	98	11	12.5	-	0	256	42	29	0.28	3	210	290	-	510	
Well A	Charlotteville Twp. XII - 3	31/ 7/64	7.1	488	94	153	-	0	346	1088	520	1.40	0	284	1620	-	2600	Former Oil - Gas Well H_2S
Well B	N. Walsingham Twp. IX - 20	31/ 7/64	7.3	292	100	353	-	0	440	483	720	0.15	0	360	1150	-	2800	"

Well GW- 1 (Well 56)	Burford Twp. IX - 22	1/ 3/65	7.7	96	13	11.5	5.3	-	261	58	19	0.06	12.0	214	292	392	520	Owner - K. Heeney Dug - 12′
,,	,,	15/ 3/65	7.6	92	15	12.0	5.9	-	243	71	16	0.20	11.0	199	292	420	550	
Well GW- 2	Burford Twp. IX - 21	1/ 3/65	7.6	80	25	10.3	5.4	-	342	61	8	0.14	1.0	280	304	402	520	Owner - A. Duck Dug - 24′
,,	,,	15/ 3/65	7.5	102	14	11.0	4.8	-	326	74	7	0.25	1.1	267	312	384	530	
Well GW- 3 (Well 96)	Burford Twp. XI - 11	1/ 3/65	7.5	68	42	11.7	3.1	-	354	96	21	1.8	tr	290	374	490	620	Owner - M. Podworny
,,	,,	15/ 3/65	7.4	116	19	11	3.0	-	322	118	21	3.15	tr	264	368	484	650	
Well GW- 4	Windham Twp. II - 11	1/ 3/65	7.7	96	15	2.9	1.3	-	274	74	6	2.7	tr	225	300	364	450	Owner - E. Donohue
,,	,,	15/ 3/65	7.5	98	8	3.2	1.1	-	342	71	5	3.35	tr	165	280	350	490	
Well GW- 5	Windham Twp. V - 14	1/ 3/65	7.7	92	14	6.8	5.4	-	354	58	13	0.08	1.7	246	290	362	475	Owner - F. Elliott
,,	,,	15/ 3/65	7.5	94	12	7.1	4.9	-	347	71	11	0.38	2.3	222	284	364	490	
Well GW- 6	Windham Twp. IX - 22	1/ 3/65	7.7	76	10	14.3	4.4	-	281	59	21	0.17	3.6	224	230	386	520	Owner - E. Augstman
,,	,,	15/ 3/65	7.5	90	13	16	4.9	-	340	15	35	0.18	tr	223	278	500	550	
Well GW- 7	Middleton Twp. TRS I-44	15/ 3/65	7.7	82	14	4.4	0.85	-	189	97	9	0.09	5.2	155	264	348	450	Owner - J. Hoskins
Well GW- 8	Middleton Twp. TRS I-43	1/ 3/65	7.5	148	6	75	3.1	-	237	36	228	0.08	2.4	194	396	754	990	Owner - G. Purser
,,	,,	15/ 3/65	7.6	70	6	33	3.3	-	189	35	42	0.09	1.6	155	198	310	460	

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				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Well GW-9	Charlotteville Twp. XII - 3	1/ 3/65	7.8	72	7	3.2	0.9	-	195	57	8	tr	1.0	160	208	248	340	Owner - D. Ronson
"	"	15/ 3/65	7.8	64	10	3.1	0.9	-	187	61	6	0.04	1.2	153	202	256	340	
Well GW-10	Middleton Twp. TRS III-14	1/ 3/65	8.1	60	6	3.2	0.9	-	166	55	8	0.07	2.6	136	212	242	310	Owner - J. Graves
"	"	15/ 3/65	7.9	58	10	3.1	0.95	-	157	61	4	0.17	2.4	129	188	242	320	
Well GW-11	N. Walsingham Twp. XI - 5	1/ 3/65	8.0	64	19	3.1	1.6	-	200	61	9	0.10	3.0	164	240	284	370	Owner - Long's Lumber Point 70'
"	"	15/ 3/65	7.8	69	12	3.4	1.8	-	192	71	6	0.88	2.5	157	222	290	380	
Well GW-12	N. Walsingham Twp. VII - 12	1/ 3/65	7.2	148	17	19	22.5	-	484	19	50	7.3	tr	396	440	554	760	Owner - E. Rohrer
"	"	15/ 3/65	7.1	152	3	37	21	-	502	20	50	44	tr	411	394	532	790	
Well GW-13 (Well 625)	S. Walsingham Twp. V - 8	1/ 3/65	7.9	88	10	3.6	6.7	-	190	90	12	tr	5.5	156	260	368	450	Owner - A. Solga Point - 8'
"	"	15/ 3/65	7.7	90	9	3.7	5.8	-	184	99	10	0.13	5.4	151	260	356	460	

Well GW-14	S. Walsingham Twp. II - 6	1/ 3/65	7.8	108	20	16.2	15	-	444	62	56	2.23	1.3	268	364	486	670	Owner - R. Poole Dug - 10′
"	"	15/ 3/65	7.6	102	21	15	9.9	-	420	79	50	0.60	1.2	246	344	462	640	
Big Creek S - 1	Burford Twp. IX - 24	3/12/64	8.0	120	28	10	4	0	388	91	25	0.85	1.3	318	416	436	630	Silica as SiO_2 - 10.9
"	"	1/ 3/65	8.0	148	28	14	4.6	0	415	141	33	0.38	-	340	488	668	-	
"	"	15/ 3/65	7.7	70	10	6.0	2.8	0	195	67	12	0.80	-	160	216	-	-	
Big Creek Tributary S - 2	Burford Twp. VIII - 23	3/12/64	7.8	88	44	10	5.4	0	388	81	19	1.20	0.8	318	402	532	620	Silica as SiO_2 - 8.3
"	"	1/ 3/65	8.0	84	16	6.6	3.4	0	249	67	12	0.28	-	204	276	357	-	
"	"	15/ 3/65	7.8	65	11	4.3	2.9	0	199	59	8	0.70	-	163	208	-	-	
Big Creek Tributary S - 3	Burford Twp. VIII - 21	3/12/64	7.5	104	36	11.5	15	0	383	57	68	0.70	0	314	410	526	680	Silica as SiO_2 - 13.2
"	"	1/ 3/65	7.7	88	15	6.6	4.8	0	290	69	18	0.71	-	238	284	350	-	
"	"	15/ 3/65	7.8	71	12	4.5	4.0	0	216	61	12	0.48	-	177	230	-	-	
Big Creek S - 4	Burford Twp. IX - 21	3/12/64	7.8	112	37	10.5	5	0	393	46	26	0.90	1.0	322	426	512	660	Silica as SiO_2 8.0
"	"	1/ 3/65	7.8	88	24	7.8	2.6	0	286	70	15	0.38	-	234	320	390	-	
"	"	15/ 3/65	7.6	69	10	5.1	2.6	0	199	65	10	0.22	-	163	214	-	-	
Big Creek S - 5	Burford Twp. XI - 11	3/12/64	7.8	96	31	5.5	3.8	0	298	101	19	0.30	0.3	244	370	446	550	Silica as SiO_2 - 6.9
"	"	1/ 3/65	7.6	100	21	4.7	2.5	0	268	108	9	0.15	-	220	336	430	-	
"	"	15/ 3/65	7.5	69	10	3.9	2.8	0	175	71	7	0.20	-	143	212	-	-	

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Source and Number	Location	Date Sampled	pH	Mineral Constituents in parts per million (ppm) (1 ppm = 1 mg/l)										Total Alkalinity as ppm $CaCO_3$	Total Hardness as ppm $CaCO_3$	Total Dissolved Solids in ppm	Specific Conductance micromhos at 25°C	Remarks
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Big Creek S - 6	Windham Twp. II - 11	3/12/64	8.2	84	36	2.5	2.3	0	268	79	14	0.40	0.6	220	360	456	460	Silica as SiO_2 - 6.6
,,	,,	1/ 3/65	8.0	88	21	4.6	2.0	0	254	77	14	0.17	-	208	308	368	-	
,,	,,	15/ 3/65	7.6	70	10	5.3	2.4	0	178	80	7	0.28	-	146	216	-	-	
Big Creek S - 7	Windham Twp. V - 14	3/12/64	7.9	80	29	2.0	2.2	0	264	74	14	0.30	0.5	216	320	364	450	Silica as SiO_2 - 7.1
,,	,,	1/ 3/65	8.0	88	17	4.3	2.2	0	246	76	14	0.24	-	202	292	345	-	
,,	,,	15/ 3/65	7.7	66	10	5.3	2.4	0	173	65	6	0.76	-	142	208	-	-	
Big Creek S - 8	Windham Twp. V - 16	3/12/64	8.1	84	26	1.5	2.2	0	261	72	14	0.30	0.6	214	320	350	440	Silica as SiO_2 - 6.3
,,	,,	1/ 3/65	8.0	80	19	4.3	2.1	0	246	82	11	0.18	-	202	280	339	-	
,,	,,	15/ 3/65	7.8	66	10	3.1	2.4	0	173	57	6	0.44	-	142	206	-	-	
Big Creek S - 9	Windham Twp. IX - 22	3/12/64	8.1	80	17	1.2	1.9	0	249	74	15	0.25	0.8	204	270	334	420	Silica as SiO_2 - 6.9
,,	,,	1/ 3/65	8.1	80	20	4.2	1.9	0	244	70	14	0.13	-	200	284	330	-	
,,	,,	15/ 3/65	7.9	66	11	3.0	2.3	0	177	57	6	0.70	-	145	212	-	-	

North Creek S - 10	Middleton Twp. TRS I-45	3/12/64	8.2	84	22	5.0	1.4	0	230	67	21	0.35	0.6	188	300	358	430	Silica as SiO_2 - 8.0
,,	,,	1/ 3/65	8.2	80	15	7.4	1.6	0	222	81	17	0.20	-	182	264	344	-	
,,	,,	15/ 3/65	8.0	82	10	5.7	1.9	0	202	74	11	1.30	-	165	246	-	-	
Big Creek S - 11	Middleton Twp. TRS I-43	3/12/64	8.2	80	22	10.5	1.8	0	244	70	29	0.30	0.8	200	290	352	460	Silica as SiO_2 - 7.1
,,	,,	1/ 3/65	8.1	80	19	8.7	1.8	0	237	67	21	0.31	-	194	280	341	-	
,,	,,	15/ 3/65	8.0	68	11	4.6	2.2	0	181	53	10	1.28	-	148	214	-	-	
Big Creek S - 12	Charlotteville Twp. XII - 2	3/12/64	8.1	80	26	10	1.8	0	242	71	25	0.40	1.0	198	310	360	460	Silica as SiO_2 - 7.1
,,	,,	1/ 3/65	8.0	80	17	9.1	2.1	0	237	76	22	0.82	-	194	272	330	-	
,,	,,	15/ 3/65	8.0	68	11	4.7	2.2	0	181	61	10	0.60	-	148	214	-	-	
Venison Creek S - 13	Middleton Twp. III - 13	3/12/64	7.9	68	29	1.6	1.6	0	234	51	16	0.40	0.5	192	290	296	380	Silica as SiO_2 - 9.6
,,	,,	1/ 3/65	8.0	80	13	4.3	1.6	0	195	74	10	0.20	-	160	256	313	-	
,,	,,	15/ 3/65	7.9	71	8	3.5	1.9	0	188	55	6	0.36	-	154	212	-	-	
Venison Creek S - 14	N. Walsingham Twp. XII - 4	3/12/64	8.1	64	31	1.0	.95	-	215	49	9	0.30	0.3	176	290	276	350	Silica as SiO_2 - 9.6
,,	,,	1/ 3/65	8.2	68	12	5.2	1.5	0	220	48	8	0.35	-	180	220	278	-	
,,	,,	15/ 3/65	8.0	70	8	3.3	1.9	0	184	53	6	0.50	-	151	208	-	-	
Big Creek S - 15	N. Walsingham Twp. VII - 13	3/12/64	8.0	80	24	11	1.75	0	237	63	26	0.85	0.6	194	300	338	450	Silica as SiO_2 - 10.4

Appendix B. Chemical Analyses of Waters in the Big Creek Drainage Basin

(locations of water sampling points are shown on Figure 39)

Source and Number	Location	Date Sampled	pH	Mineral Constituents in parts per million (ppm) (1 ppm = 1 mg/l)										Total Alkalinity as ppm $CaCO_3$	Total Hardness as ppm $CaCO_3$	Total Dissolved Solids in ppm	Specific Conductance micromhos at 25°C	Remarks
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Iron (Fe)	Nitrate (N)					
Big Creek S - 15	N. Walsingham Twp. VIII - 13	1/ 3/65	8.0	84	12	9.1	1.9	0	237	78	17	1.56	-	194	260	343	-	
"	"	15/ 3/65	8.0	67	10	5.4	2.6	0	180	52	11	1.40		147	210	-	-	
Big Creek S - 16	S. Walsingham Twp. V - 9	3/12/64	7.9	80	26	10	1.8	0	227	69	24	0.80	0.6	186	310	324	440	Silica as SiO_2 - 8.8
"	"	1/ 3/65	8.0	84	11	8.9	1.5	0	230	78	21	1.02	-	188	256	330	-	
"	"	15/ 3/65	8.0	67	9	4.8	2.0	0	177	55	10	1.72	-	145	206	-	-	
Venison Creek S - 17	S. Walsingham Twp. V - 8	4/12/64	8.0	64	19	1.0	1.3	0	205	43	10	0.51	0.4	168	240	262	350	Silica as SiO_2 - 9.9
"	"	1/ 3/65	8.1	56	20	3.8	1.1	0	200	61	9	0.92	-	164	224	264	-	
"	"	15/ 3/65	8.0	66	8	3.1	1.6	0	170	55	6	1.52	-	139	192	-	-	
Big Creek S - 18	S. Walsingham Twp. 11 - 7	4/12/64	8.1	72	22	7.5	1.4	0	227	60	21	0.65	0.5	186	270	324	425	Silica as SiO_2 - 8.8
"	"	15/ 3/65	8.0	64	10	5.0	2.1	0	175	47	9	2.20	-	143	200	-	-	

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